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Proceedings of an international symposium
El Batan, Mexico, 1-3 October 1973

Editors: Reginald MacIntyre/Marilyn Campbell

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Editors: REGINALD MACINTYRE/MARILYN CAMPBELL

This symposium was co-sponsored by the Centro Internacional de Mejoramiento de Maiz y Trigo, the University of Manitoba, and the International Development Research Centre.

*The views expressed in this publication are those of the individual author(s) and do not necessarily represent the views of the International Development Research Centre.

ISBN 0-088936-028-6
UDC: 633.1
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Head Office: 60 Queen Street, Box 8500, Ottawa, Canada K1G 3H9
Microfiche Edition $1

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Foreword

When the International Development Research Centre announced in November 1971 its support of a major research program into triticale, the objective was "to improve the properties of the man-made cereal grain, Triticale, and to broaden its use." The announcement continued: "The objective of this scientific manipulation (crossing wheat and rye) of naturally occurring grains is to produce a new food crop, the agronomic characteristics and nutritional value of which will be superior not only to those of either of its parents, but to all other cereal grains, particularly those grown in food-deficient areas of the world where climatic conditions are often unfavourable for cereal grain production. It is anticipated that Triticale will provide a valuable new source of protein and essential nutrients for many people of the developing world."

Are we nearing our stated goal? I think so. The main purposes of the 1–3 October 1973 symposium reported on in these proceedings were to review the current state of knowledge of triticale breeding and to exchange information. The work of many people, including plant breeders, agronomists, geneticists, etc., as reported in these proceedings, has brought triticale to a new phase — putting bags of seeds out for farmers to pick up and plant. And so, this first International Triticale Symposium essentially launches this new grain for mankind. However, there are many risks involved, and the scientists are going to have to work closely with the cultivators to ensure a successful transition from the laboratory to the farmers' field.

The symposium was divided into three main themes: the initial sessions were devoted to discussing the important triticale research programs in the various developed countries; the second portion was devoted to new triticale programs in the less-developed countries of the world; and the third theme concerned the various major problems confronting the plant breeder, agronomist, etc.

We at IDRC felt that we should give triticale five years, and if it would outyield wheat by 30% we would consider the job well under way. The evidence now is that triticale has that potential and, in some instances, it has outyielded wheat, so the time has come to drop the triticale–wheat comparisons.

What seems important now is the adaptability of triticale in areas not easily adapted to wheat: examples of this are the Himalayas suggested by Srivastava, and in Ethiopia as suggested by Pinto, its potential in lighter soils even under irrigation, etc. As well, we should attempt to develop triticale's own standards of yield comparisons. When this is done triticale will truly have come into its own.

The success of this symposium is the result of much hard work and dedication behind the scenes. Starting with the early planning, CIMMYT's Head of the Triticale Program, Dr Frank J. Zillinsky, has been a key individual in identifying participants and developing the program. Special thanks first go to the Director General of CIMMYT, Haldore Hanson, for agreeing to host the symposium. Mr Hanson personally welcomed the participants on the first day of the discussions, pointing out that the reason for CIMMYT, the reason for the symposium, and in fact the reason most of those present were pursuing their particular line of research, was to meet the rising demand for food in the world. Obviously this is no easy task, Mr Hanson added, since the world population increases by 2% per year, or 77 million people, and by another 0.5% in developing countries where the food shortage is most critical. Posing questions for the participants, Mr Hanson asked: How will triticale contribute to this need for more food? Will it produce more food or more feed or more forage on the existing land surface that is used for agriculture? Will it contribute an enriched nutritional product on the present agricultural land — a nutritional value that will support a larger population? Will it offer the possibility of pushing back frontiers of today's agricultural area into the colder regions, or the hotter regions, or the drier regions of the world so that the total agricultural area of the world is enlarged?

Mr Hanson felt that the answer to all questions will be yes, triticale can contribute in most or all of these areas to help feed mankind.

Other CIMMYT staff greatly contributed to the success of the meeting: Dr Gregorio Martinez, the Communications Director, Miss Linda Ainsworth of the Visitors and Seminars Service, and other efficient but unidentified people in the sound and projection booth, displays staff, and many more.

It is significant that this symposium was held at CIMMYT in El Batan — first because of the significant contribution CIMMYT scientists have made to the development of triticale, in partnership with a group of equally talented scientists from the University of Manitoba, and second because the building where the meeting was held was virtually surrounded by fields of triticale, a most fitting setting for the first International Triticale Symposium, to which were invited experts from more than 15 countries to discuss the status of triticale research throughout the world and to decide "where do we go from here?"

Close to 100 participants registered, representing many scientific disciplines. This multidisciplinary approach gave plant breeders a chance to discuss the problems and concerns of the geneticist, the nutritionist had an opportunity to present his side of the story to the agronomist, and so on. This unique interchange of ideas will hopefully make everyone aware of the problems and interests common in many countries of the world.

In addition to the papers included in these proceedings, three important contributions were made, the texts of which are not, however, available for inclusion. Two CIMMYT staff members, Drs Eva Villegas and Reinald Bauer, spoke on the nutritional aspects of triticale varieties. The potential of triticale flour in the food industry was discussed by Charles Briggs of the Triticale Foods Corporation of Muleshoe, Texas.

The symposium spanned three full days, and the material was presented and discussed in the order the papers appear in this publication. The various session chairmen did an excellent job of keeping the discussions running smoothly. The chairmen were: Drs E. N. Larter, George Dion, Gerbrand Kingma, K.-D. Krolow, Keith Finlay, and Walter Bushuk.

Unfortunately, Dr K. Budin of the USSR was unable to attend to deliver his paper on the status of triticale research in Russia. As well, Dr Pao of the People's Republic of China was unable to attend the meeting. He was to report on triticale in his country.

I am quite confident that this meeting and this publication will go a long way in getting this new grain growing and thriving throughout the world. My organization, the International Development Research Centre, and the Canadian International Development Agency, are proud to be associated with the triticale work at CIMMYT and the University of Manitoba.

W. DAVID HOPPER
General Chairman
International Triticale Symposium

(Dr Hopper is President of the International Development Research Centre, Ottawa, Canada.)

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Historical Review of the Development of Triticale

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MÜNTZING, ARNE. 1974. Historical review of the development of triticale, p. 13–30. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract In 1875, a Scottish plant breeder named Wilson was the first to obtain and describe a sterile F_1 triticale hybrid, a cross between wheat and rye. In 1884 the *Rural New Yorker* contained several articles by Carman (an American plant breeder) about crosses between wheat and rye. Most of his crosses were unsuccessful and produced only maternal plants, but also one true F_1 hybrid. The first fertile triticale was not reported until 1888 by a German worker, Rimpau.

Major work on triticale was carried on between 1918 and 1934 at the Agricultural Experimental Station at Saratov in southeast Russia. In 1918 a mass appearance of natural F_1 hybrids between wheat and rye occurred at Saratov, all of which were male-sterile and incapable of self-pollination. Hybrid derivatives were later (1927 and 1928) observed that were more or less intermediate between wheat and rye but were true-breeding and rather fertile.

Meister, in 1928, gave a botanical description of so-called balanced wheat–rye hybrids and designated the new species combination as *Triticum secalotricum saratoviense* Meister.

Cytological analysis was carried out in 1930 and 1931 by Levitsky and Benetz who made a careful study of mitosis and meiosis and stated that the somatic chromosome number in all three families was 56 and therefore the constant intermediate fertile rye–wheat hybrids were definitely amphidiploids of bread wheat and rye.

In 1934, Lebedoff obtained a wheat–rye amphidiploid and was the first to report the occurrence of aneuploidy in such material.

The hypothesis that the wheat–rye amphidiploid must result from an apogamous development of unreduced ovules in the primary hybrids, followed by immediate chromosome doubling, was abandoned in 1936 because of new empirical data of Müntzing. He succeeded in 1935 in getting a seed sample of Rimpau's fertile wheat–rye hybrid. Several seedlings had 56 or ±56 chromosomes and consequently Rimpau's hybrid was obviously an octoploid strain of triticale and the oldest one known. The Rimpau strain had retained a perfect constancy during 45 years of cultivation before the true nature of the new amphidiploid species became known.

The name "triticale" was used for the first time in a paper by Lindschau and Oehler and had been proposed to them by Tschermak.

The archaic period of work with triticale came to an end after 1937 when experimental doubling by means of colchicine had been discovered and new strains of triticale could be produced in unlimited quantities.

The results of more recent triticale research work are also discussed.

Résumé C'est un phytosélectionneur écossais, du nom de Wilson, qui obtint et décrit pour la première fois en 1875 un triticale stérile F_1 hybride, résultant du croisement blé × seigle. En 1884, le *Rural New Yorker* publia une série d'articles de Carman, un phytosélectionneur américain, sur ces mêmes croisements. La plupart de ceux qu'il avait tentés étaient restés infructueux, ne reproduisant que la mère, mais l'un d'entre eux avait donné un véritable hybride F_1. Ce n'est qu'en 1888 qu'un chercheur allemand, Rimpau, a signalé le premier triticale fertile.

La Station Expérimentale Agricole de Saratov, en Russie du Sud-Est, a effectué des travaux essentiels sur le triticale entre 1918 et 1934. Dès 1918, une production importante d'hybrides naturels F_1 entre blé et seigle était intervenue à Saratov, tous mâles stériles et incapables de s'auto-féconder. En 1927 et 1928 on constata la présence de dérivés hybrides plus ou moins intermédiaires entre le blé et le seigle mais se reproduisant en race pure et plutôt fertiles.

En 1928, Meister donnait une description botanique de ce qu'il appelait les hybrides équilibrés blé × seigle, et il baptisait cette nouvelle combinaison d'espèces *Triticum secalotricum saratoviense* Meister.

Levitsky et Benetz effectuèrent en 1930 et 1931 des analyses cytologiques et une étude soigneuse de la mitose et de la méiose, à l'issu de quoi ils établirent que le nombre de chromosomes somatiques des trois familles était de 56, et que par conséquent les hybrides seigle × blé, fertiles et fixés, étaient indubitablement des allopolyploïdes du blé tendre et du seigle.

En 1934, Lebedoff obtint un allopolyploïde blé × seigle et fut le premier à signaler une manifestation d'aneuploïdie dans ce matériel végétal.

L'hypothèse selon laquelle l'allopolyploïde blé × seigle résulte obligatoirement du développement apogamétique des ovules non réduites chez les hybrides primaires, suivi immédiatement d'un doublement des chromosomes, a été abandonnée en 1936 du fait des nouvelles données empiriques obtenues par Müntzing. Il avait réussi en 1935 à se procurer un échantillon de semences de l'hybride fertile blé × seigle de Rimpau. Plusieurs des plantules obtenues avaient 56 ou ± de 56 chromosomes, ce qui prouvait de toute évidence que l'hybride de Rimpau était une souche octoploïde de triticale, la plus vieille connue. Cette souche de Rimpau s'était parfaitement perpétuée durant 45 ans de culture avant que l'on connaisse enfin la véritable nature de cette nouvelle espèce allopolyploïde.

Ce sont Lindschau et Oehler qui ont utilisé pour la première fois dans un texte ce nom de "triticale" qui leur avait été proposé par Tschermak.

L'époque archaïque des travaux sur triticale a pris fin après 1937, lorsque l'on a réalisé le doublement expérimental des chromosomes grâce à la colchicine et que l'on a pu produire en quantités illimitées de nouvelles souches de triticales.

L'auteur expose également les résultats de travaux de recherche plus récents sur le triticale.

IN 1875 a Mr Wilson reported to the Botanical Society in Edinburgh that in a series of attempted crosses between wheat as the female parent and rye as the male, he had succeeded in obtaining true hybrids of the kind we are now familiar with.

In 1884 the American plant breeder Carman published several communications in the periodical *Rural New Yorker* about crosses between wheat and rye. Most of his crosses were unsuccessful and gave only maternal plants, but in one instance the cross resulted in a true F_1 plant. This is evident from a picture (Fig. 1) originally published in the *Rural New Yorker* and later reprinted in the *Journal of Heredity* by Leighty (1916). Besides the morphological appearance, the very low fertility was evidence of true hybridity. This was also borne out by the characteristic rye pubescence on the peduncle, which was present in hybrid plants derived from wheat as the female parent.

Triticales first came on the scene thanks to the work of a research team at the Agricultural Experiment Station of Saratov in the southeastern part of Russia. Approximately

FIG. 1. Wheat–rye. This is the first illustration published of a wheat–rye hybrid, and represents Carman's own work. It appeared as Fig. 339 in the *Rural New Yorker* on 30 August 1884.

during the period 1918 to 1934 the director of the institute, G. K. Meister, and his associates were active in the field of wheat–rye hybridization.

In 1918 an extraordinary phenomenon was witnessed in their experimental fields — a mass appearance of natural F_1 hybrids between wheat and rye in a number of plots of winter varieties of wheat (Meister 1921). In one wheat plot about 20% of the plants were hybrids and altogether many thousands of natural wheat–rye hybrids were observed. They were derived from early flowering wheat varieties that flower rather openly in the dry continental climate of Saratov. Moreover, the wheat plots had been separated from each other by protecting rows of rye, supposed to prevent cross pollination between the wheat varieties. The hybrids were all male-sterile and incapable of self-pollination. Hence, the thousands of seeds collected from the vast number of F_1 plants were generally products of spontaneous back-crosses to wheat or rye.

Hybrid derivatives were later observed that were more or less intermediate between wheat and rye, but in spite of that, were true-breeding and rather fertile (Fig. 2). Such so-called balanced wheat–rye hybrids were suspected to be polyploid as indicated in papers from 1927 and 1928; and in 1930 Tumyakov published a report about fertility and morphology of these "wheat–rye hybrids of balanced type." Meister (1928) gave a botanical description of this material (see Levitsky 1932) and designated the new species combination as *Triticum secalotricum saratoviense* Meister. He also emphasized the importance of the new products for plant-breeding work and even published preliminary results concerning baking properties in this material, which he believed nobody had seen before.

The cytological analysis of this material was carried out by Levitsky and Benetzkaja (1930, 1931) who made a careful study of mitosis and meiosis. They stated that the somatic chromosome number was 56 (Fig. 3) in three different families. Thus, the constant intermediate fertile rye–wheat hybrids were definitely amphidiploids of bread wheat and rye.

Investigations of the mode of meiosis in the pollen mother cells, as well as on the female side, revealed a frequent occurrence of irregularities caused by the presence of univalent chromosomes (Fig. 4*a*). This was observed in all three of the families studied and was therefore regarded to be characteristic of rye–wheat amphidiploids in general.

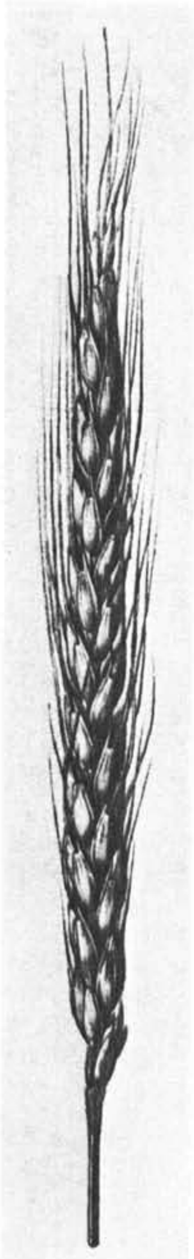


FIG. 2. Later hybrid between wheat and rye, fertile and true-breeding.

This disturbed pairing could not depend on lack of homology, and must therefore be assumed to have had other causes, either a general incompatibility between the parental chromosome sets, or an antagonism between the female cytoplasm and the male chromosome set, which represented another genus.

Levitsky and Benetzkaja also discussed the mode of origin of the amphidiploids and had to base their arguments on the fact that all the primary wheat–rye hybrids at Saratov were completely male-sterile. Under such circumstances they had to assume an apogamous development of F_1 ovules with a somatic number of chromosomes, and that this chromosome set was then doubled in the first division of the egg cell.

This view was reluctantly accepted by other workers writing about the amphidiploid wheat–rye hybrids during 1930–36. Lebedeff (1934), while working at a station in Ukraina, obtained a wheat–rye amphidiploid that was essentially similar to those at Saratov. He was first to report the occurrence of aneuploidy in such material. A few plants had less than 56 chromosomes. Lebedeff, when discussing the reduced fertility of the wheat–rye amphidiploids, pointed out that poor fertility and other disturbances are characteristic of inbred lines of rye. He therefore suggested that such unfavourable properties in the amphidiploids might be avoided by the use of fertile and vigourous inbred lines of rye in the primary cross. He also emphasized the importance of choosing the right varieties of wheat for the primary crosses. He did not believe that cytoplasmic differences between wheat and rye could be important, because backcrossing of primary wheat–rye hybrids to rye had led to quite regular and fertile rye plants in spite of their wheat cytoplasm. Lebedeff also demonstrated the formation of unreduced ovules with 28 chromosomes in primary hybrids. After pollination with rye, a plant with 35 chromosomes had been obtained. He suggested that the occurrence of such ovules should also be utilized for the production of new amphidiploid strains after pollination of primary hybrids with the pollen of already existing amphidiploids. He also outlined other ways for the future breeding of the new material, for which he suggested the name "Tritisecale."

Lebedeff did not publish anything more on his octoploid triticale material. His work may

FIG. 3. *Triticum vulgare* × *Secale cereale*. Constant intermediate rye–wheat hybrid. Somatic plate of an individual from F_1. Chromosome number 56. Enlargement ×2700.

have been stopped by the approach of the Lyssenko regime and the same influence may have also counteracted and stopped the pioneering work carried out by the Meister group in Saratov.

The hypothesis that the wheat–rye amphidiploids must result from an apogamous development of unreduced ovules in the primary hybrids, followed by immediate chromosome doubling, was abandoned in 1936 when new empirical data were published (Müntzing 1936). In 1931 I came to the Swedish Seed Association as head of a new laboratory for chromosome research and induction of polyploidy in cultivated plants. In my program, work with wheat–rye amphidiploids was also included. In the summer of 1935, I had a quantity of F_1 plants representing 15 different cross combinations. In one of these combinations, representing Swedish varieties of wheat and rye, I observed in one of the F_1 plants that single anthers had dehisced and that these anthers contained pollen of good quality. In this plant part of the anthers in three different heads were fertile, whereas the other heads of the same plant were male-sterile as usual. The entire F_1 material available (65 plants) was scrutinized, and in a second plant a single flower with dehiscing anthers was discovered. It belonged to the same cross-combination as the first, partially male-fertile F_1 plant, but in all the other 14 cross-combinations no flowers with dehiscing anthers could be detected.

Pollen samples from the dehiscing anthers (Fig. 4*b*) showed that the percentage of apparently normal pollen grains in these anthers ranged from about 20 to 60%. Measurements revealed that the pollen grains were quite large and therefore probably unreduced. This was verified by using this pollen for controlled self-pollination. From a head thus treated a single kernel was obtained. It germinated and gave rise to a plant with 56 chromosomes, which was the starting point of a new strain of octoploid triticale.

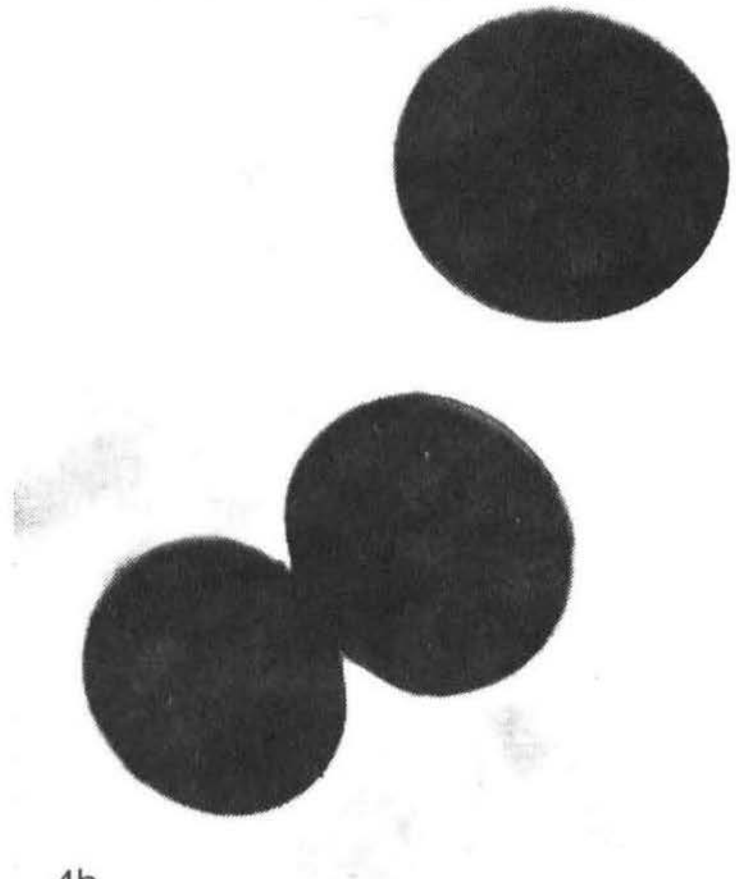
In this case the production of a new triticale strain was made possible either by the spontaneous formation of small somatic sectors with a doubled chromosome number, including anthers as well as ovules, or perhaps

4a

FIG. 4*a*. Meiosis in pollen mother cells showing presence of univalent chromosomes.

even by quite local areas of chromosome doubling leading to single dehiscing anthers, or parts of anthers, with unreduced pollen. Such an occurrence may, of course, easily be overlooked but probably represents a mechanism of general importance that had been at work also in the previous cases of spontaneous origin of octoploid types of triticale. Thus, the rather unlikely hypothesis of apogamous development, followed by chromosome doubling, became superfluous.

Though the octoploid triticale types discovered at Saratov were the first to be scientifically explored, another strain of the same kind had arisen in Germany in 1888. The breeder Rimpau, just like Carman in the United States, made crosses between wheat and rye, and in one of the hybrids obtained, one of the heads produced 15 kernels. In this head there must have been a doubled sector since 12 of the kernels gave rise to fertile plants of uniform appearance (Rimpau 1891). The new constant strain (Fig. 5–7) was at first grown by Rimpau but was shortly afterwards included in the comprehensive material cultivated in a plant-breeding garden in Halle. Guided by serological results that had been obtained with this strain by Moritz (1933), and that indicated the presence of wheat as well as rye proteins, I succeeded, in 1935, in getting a seed sample of Rimpau's fertile wheat–rye hybrid. Several seedlings had 56 or ± 56 chromosomes and, consequently, Rimpau's hybrid was obviously an octoploid strain of triticale and the oldest one known. This was also verified by Lindschau



4b

FIG. 4*b*. Pollen samples from dehiscing anthers.

and Oehler (1935). Of particular interest in this case is the fact that the Rimpau strain had retained a perfect constancy during the 45 years of cultivation before the true nature of this new amphiploid species became known.

As far as I know, the name triticale was used for the first time in 1935 in the paper by Lindschau and Oehler. This name had been proposed to them by Tschermak, one of the three rediscoverers of Mendel's laws. Tschermak carried out much hybridization work with cereals and, for instance, succeeded in producing an amphidiploid between tetraploid wheat and *Aegilops ovata* that he named *Aegilotricum* (Tschermak and Bleier 1926). There is reason to believe that the name triticale was coined during verbal discussions between Tschermak and his German colleagues at the Müncheberg Institute for Plant Breeding Research. In their paper Lindschau and Oehler also point out that it would be convenient to distinguish between different strains of triticale by adding the author's name. Thus, "triticale Rimpau," "triticale Meister," etc.

During a 5-year period in the 1930's I had the opportunity of devoting much of my time to work with triticale. The results gathered were reported in a paper published in 1939. Since this paper is characteristic of the status and problems of research in triticale at that time, I shall mention some of the results obtained.

My material consisted of six strains of triticale (Fig. 5–7, 8–10), of which only one

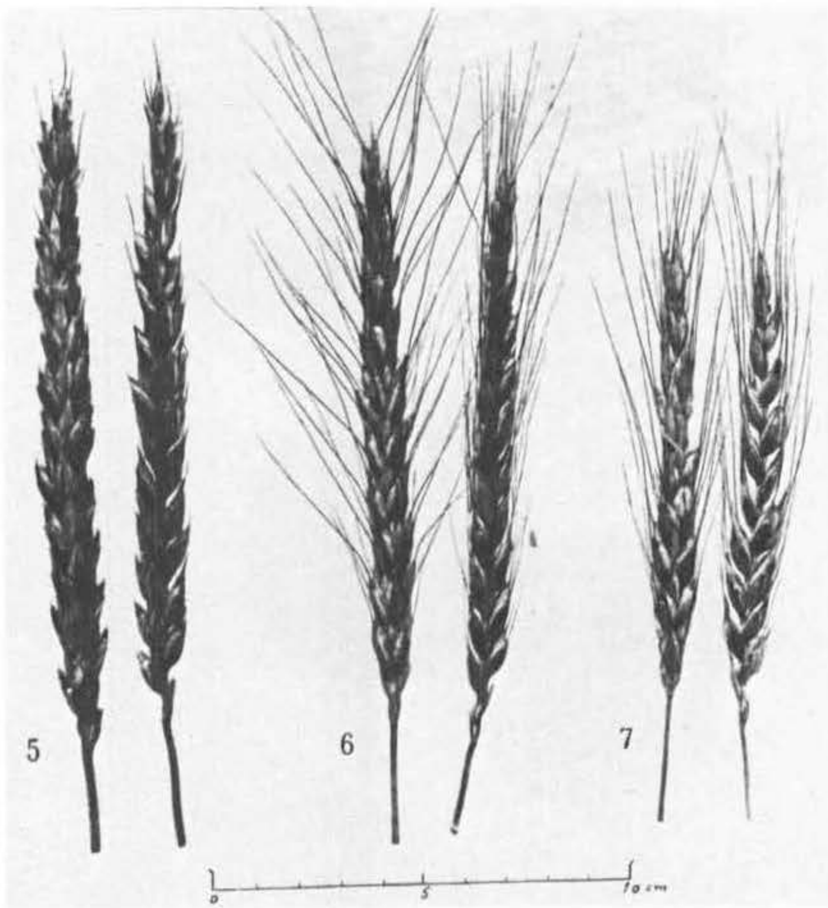


FIG. 5–7. Ears of three of the six constant triticale strains studied. Fig. 5, Triticale A; Fig. 6, Triticale B; Fig. 7, Triticale C. Fig. 5 and 6 represent the types produced by Rimpau; Fig. 7 is of Russian origin. The cross combination most extensively studied is that between strains A and C (Fig. 5 and 7).

represented a union of Swedish wheat and rye and the other strains had been produced in other countries (Germany, Russia, and the United States). The six strains were all partially sterile, but the degree of sterility was different in different strains. The triticales also differed significantly in vigour, in the degree of meiotic irregularity, and in physiological and chemical respects such as winter hardiness, earliness, and baking capacity. A baking test with triticale Meister gave a surprisingly good result, the bread volume being larger than in the best bread wheat varieties available for comparison.

As soon as more than one triticale strain had been obtained, recombination breeding was started, at first by intercrossing triticale Meister and triticale Rimpau. To my surprise, crosses between different triticales succeeded with difficulty, the average seed set being as low as 5%. There were also reciprocal differences in this respect.

Inter-strain hybrids were found to be vigourous. In one of the crosses that was studied in detail, the F_1 plants were taller than the average height of the parents, but were more sterile than the parents and showed a higher degree of nonpairing of the homologous chromosomes at meiosis. In F_2 there was a significant decrease in vigour and, on

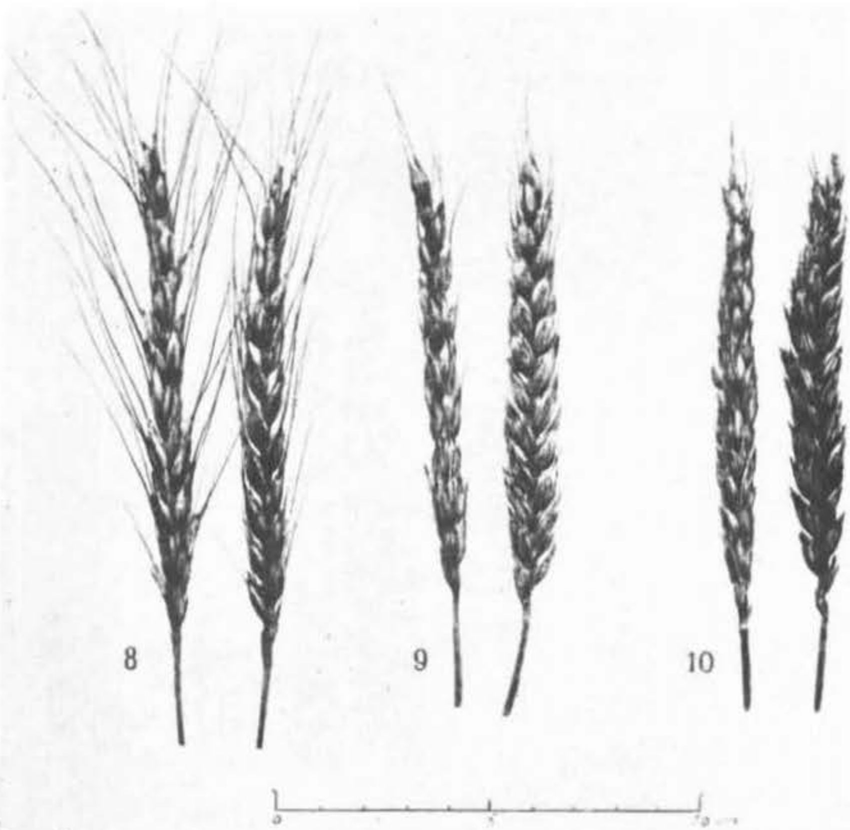


FIG. 8–10. Ears of three of the six constant triticale strains studied. Fig. 8, Triticale D; Fig. 9, Triticale E; Fig. 10, Triticale F. Fig. 8 is of Russian origin, Fig. 9 is the strain of Taylor and Quisenberry, and Fig. 10 represents Triticale Svalof (a combination of "Solvete III" and "Midsomarråg").

an average, the plants were still more sterile than the F_1 plants. However, in later generations fertile recombinants could be obtained that greatly surpassed the parents in yield (Müntzing 1948).

New triticale strains were not only produced by crosses between constant strains already existing, they were also derived from crosses between triticale and bread wheat and selection of new triticale types with recombined wheat chromosomes in the offspring. New triticale strains could also be obtained by pollination of primary wheat–rye hybrids with triticale pollen (Fig. 11–13). In this way, some of the unreduced ovules in the primary hybrids could be picked up by male gametes having the same chromosome number, 28. This method led to new plants with 56 chromosomes that were heterozygous for the wheat as well as the rye chromosomes. A very marked segregation was obtained in the offspring, but this segregation was complicated by chromosomal irregularities.

Unreduced gametes in hybrids between wheat and rye had been utilized earlier — by myself in hybrids between *Triticum turgidum* and rye that, in the absence of triticale strains at that time (1933), were pollinated with hexaploid bread wheat. The result was triple hybrids with 42 chromosomes, carrying the complete haploid genomes of rye and the two wheat species (Müntzing 1935). As is evident from Fig. 14, the morphological appearance of the triple hybrids represented a harmonious union of the three components.

Similar work was later carried out by

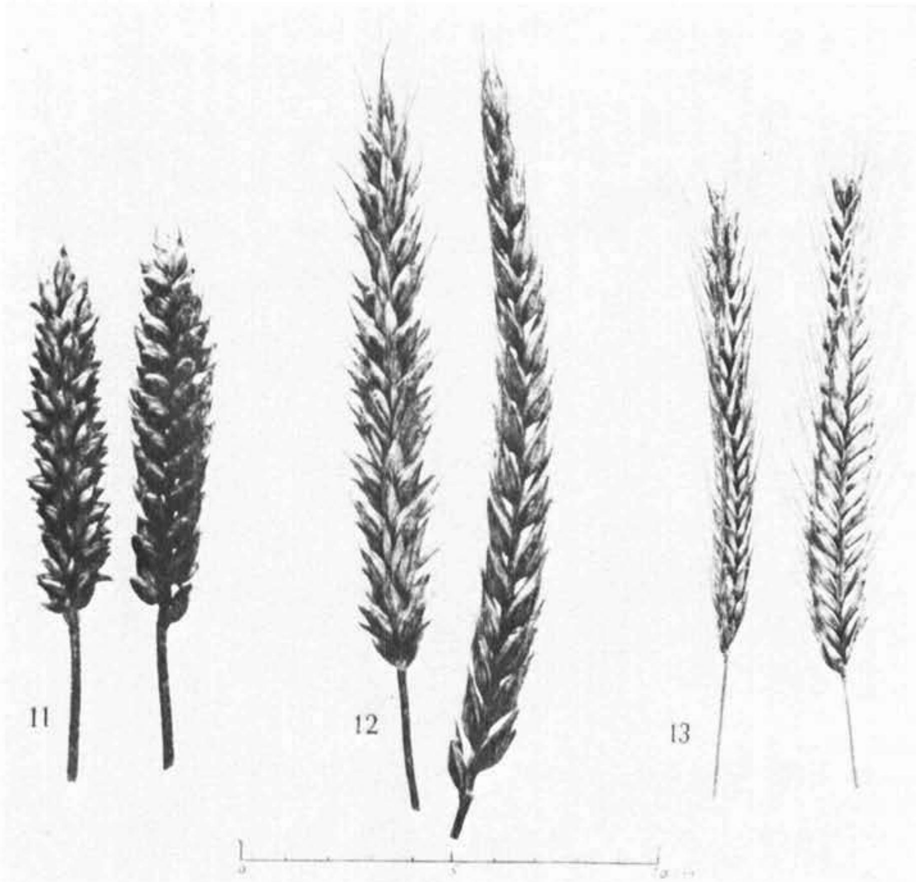


FIG. 11–13. Ears of a new triticale product (Fig. 12) in comparison with ears of wheat (Fig. 11) and rye (Fig. 13). Fig. 11 represents "Solvete III," Fig. 13, "Stalrag," and Fig. 12 two different triticale plants from the I_2 generation of a new triticale heterozygote. This heterozygote arose from pollination of a hybrid between Swedish wheat and rye with triticale pollen. The large ear and kernel dimensions are conspicuous. Fig. 11–13 are directly comparable to Fig. 5–10.

Nakajima (1942, 1951, 1952, 1953, 1958, 1961, 1965) in Japan, and described in numerous publications. To triticale breeders it is of more interest to know that a similar procedure is nowadays successfully used by the Russian breeder Shulyndin in Charkov. By pollination of primary hybrids between bread wheat and rye with hexaploid triticale, Shulyndin (1972) has obtained especially good triticale types. These products he regards as representing a complete synthesis of the three species involved, with the exception that the D-genome of bread wheat has been eliminated.

Recent Work

The archaic period of work with triticales came to an end after 1937 when experimental chromosome doubling by means of colchicine had been discovered and new strains of triticale could be produced in unlimited quantities. However, in many countries, and especially in Europe, World War II seriously hampered research activities. In the Soviet Union, moreover, the Lyssenko regime was a serious obstacle. Nevertheless, some work with octoploid triticale was still continued

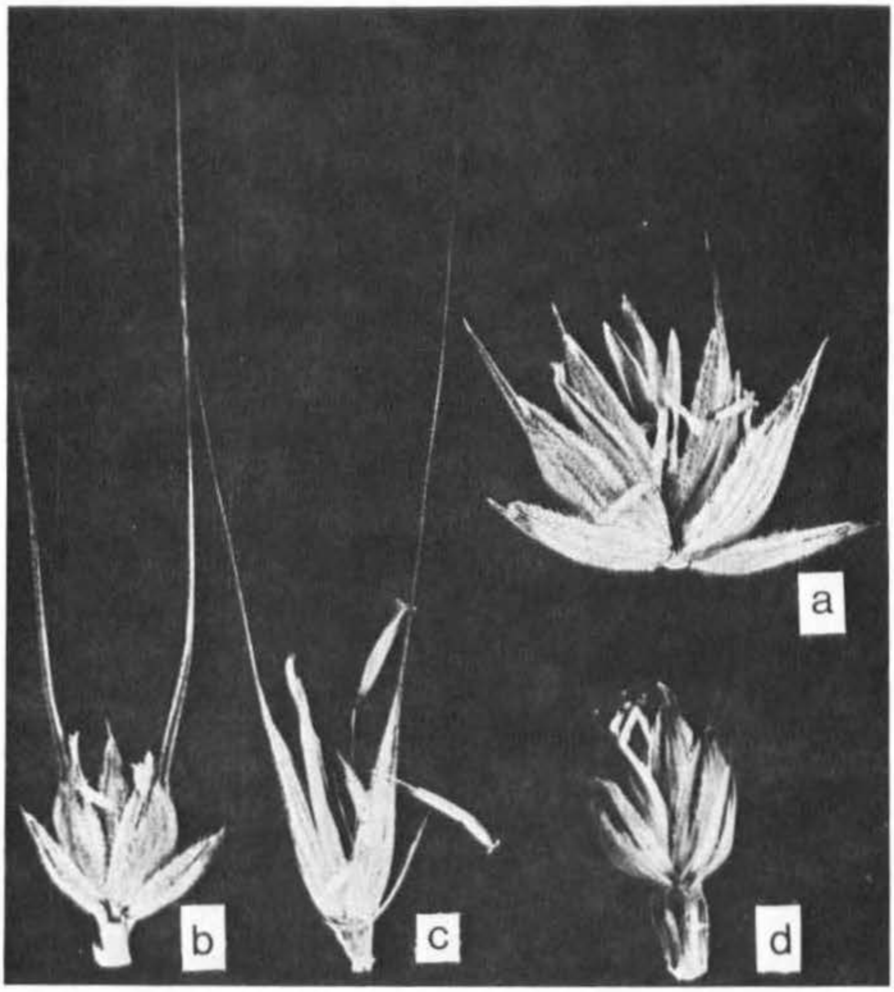


FIG. 14. Spikelets of the triple hybrid (*a*) and the parent species, *Triticum turgidum* (*b*), *Secale cereale* (*c*), and *Triticum vulgare* (*d*). ×20.

and later expanded when conditions became more favourable.

I would like to briefly summarize a few of the results obtained with octoploid triticale during the last few years. It is, of course, easiest for me to base this information on experience gathered from my own material (Müntzing 1948, 1956, 1957, 1958, 1963, 1966, 1970), but special reference should also be made to the comprehensive work by Ingold et al. (1968).

The first primary strains were only theoretical curiosities with a yield much below the level reached by high-bred varieties of wheat and rye. However, breeding work with octoploid triticale led to considerably improved strains that in some field trials, especially on light or sandy soils, gave yields equal to those of bread wheat. Kernel size in these triticale lines was superior to that of wheat, and this fact compensated considerably for the lower seed set of the triticales. Seed quality was also improved to the point of being comparable to wheat. Nevertheless, even the best octoploid strains could not compete successfully with hexaploid wheat.

In part, this was due to lack of sufficient straw stiffness in most of the octoploids, which caused lodging at higher amounts of nitrogen fertilization. Under such circumstances spraying with the chemical CCC increased the straw stiffness of the triticales considerably. It also helped counteract the reduction in yield caused by lodging. No doubt, however, judging from experience made in other countries, a more effective escape from lodging was to breed new material of octoploid triticale with sufficient straw stiffness. Even if this goal could in part be attained, there still remained the main difficulty: an unsatisfactory number of kernels per spikelet, a reduced fertility, the causes of which are not yet entirely clarified.

One main factor, however, is the occurrence of more or less high rates of aneuploidy in the octoploid strains. The correlations between sterility, meiotic disturbances, and rate of aneuploidy have been studied by several workers and were recently discussed in a paper by Weimarck (1973). She concludes that in bulk populations, as well as in progenies of euploid plants, recombined strains are characterized by lower degrees of aneuploidy than primary strains. The recombined strains also have higher fertility and a more stable meiosis than the primary strains. A close relationship was found between somatic chromosome number and fertility, the euploids having clearly higher fertility than the aneuploids. It should be observed, however, that no direct correlation has been found between the degree of meiotic disturbances in a plant and its fertility.

Judging from the results obtained, the present level of aneuploidy in the best octoploid strains (in my material about 30%) can certainly be pushed down still further by recombination and selection, and this must lead to increased productivity.

The economical importance of octoploid triticale is also strongly influenced by kernel quality — not only the degree of shrivelling of the seeds but also the biochemical properties and their relationship to bread-baking capacity. Therefore, in the breeding work during the last decades it became increasingly urgent to pay attention to analytical data gathered by the cereal chemists. It is now not only a question of test weight and raw protein contents, but many other, more sophisticated biochemical variables are involved. A serious weakness in the octoploid triticale types, so far tested, is the enzymatic processes in the kernel and the tendency to pregermination, if the ripening crop is exposed to humid condition before harvest. However, triticale strains react differently to such conditions, and rye varieties that are resistant to pregermination are now available and may be used for the production of new triticales.

A general conclusion in this field of cereal chemistry is also that scales and standards that are well suited for wheat varieties cannot automatically be used for the evaluation of triticales. Test values, which in bread wheat would indicate that the material is entirely unfit for baking, have little significance for triticale. In a recent case quite good triticale bread was prepared from flour having very poor values of alpha amylase, according to wheat standards.

Basic cytogenetic work in octoploid triticale has also led to various important results. By improved technical methods, Pieritz (1966, 1970) succeeded in distinguishing morphologically between wheat and rye chromosomes and confirmed other indirect evidence that in octoploid triticales (in contrast to hexaploids) the univalents occurring at meiosis are predominantly rye chromosomes. The rye chromosomes, therefore, have a tendency to become eliminated in contrast to the wheat chromosomes that are rarely unpaired. Pieritz also showed that there is a strict selection against aneuploidy among the male gametes, whereas all kinds of deviating chromosome constitutions are transmitted by the ovules.

Another cytogenetic phenomenon, observed by various workers, is that in octoploid triticale there are not only meiotic but sometimes also mitotic disturbances, that lead to chromosome deviations in somatic cells (Müntzing 1957). For this reason, the total number of chromosomes in the pollen mother cells may also, in some instances, be higher or lower than it should be. This phenomenon, which also occurs in hexaploid triticale (Orlova 1970), is not unique for triticale but has also been observed and analyzed in various species hybrids (Plotnikowa 1932; Bleier 1934; Lange

1971) and in inbred lines of rye (Rees 1955).

Another finding of interest is that spontaneous reversions to haploidy may sometimes occur in triticale (Müntzing et al. 1963). As a rule, however, this phenomenon is quite rare or entirely absent, but in some strains, reversions to haploidy have been observed more frequently.

It is possible that the interest in triticale as a potential new crop would have tapered off entirely if the efforts had been limited to octoploid material. However, this has been successfully prevented by the enormous development of hexaploid triticales and by the crosses between octoploids and hexaploids. Although this explosion is much more recent than the octoploid story, it may now be worthwhile to look back and point out some of the main features in this phase of the life of triticale.

Hybridization between tetraploid wheat and rye was started about 60 years ago. The first hybrid was probably *Triticum dicoccoides* × *Secale cereale*, which was produced by Jesenko in 1913. The first hybrid between *Triticum durum* and rye was described in 1924 by Schegalow (Plotnikowa 1932). The first amphidiploid between tetraploid wheat and rye was reported in 1938 by Derzhavin. In this case it was a union of *Triticum durum* with *Secale montanum*. Of more interest from the breeding point of view was O'Mara's (1948) amphidiploid between *T. durum* and cultivated rye and Nakajima's (1950) combination of *Triticum turgidum* and rye. A more concentrated effort of producing a broader and more variable material of hexaploid triticale was made by Sanchez-Monge and Tijo (1954) and Sanchez-Monge (1956, 1958) in Spain. This work was primarily made to get triticales of good grain quality as a substitute for a mixture of wheat and rye that is rather widely cultivated in certain regions of Spain. Sanchez-Monge and his co-workers found that it was obviously impossible to obtain, directly, a 42-chromosome triticale with good properties but believed that it would be possible to improve this material by recombination and selection.

That their optimism was justified has been amply demonstrated by the excellent work carried out at the University of Manitoba during the last two decades. This work has represented a successful combination of basic cytogenetic work with intensive breeding efforts and was carried out by such men as Jenkins, Shebeski, Evans, Welsh, and Larter (Larter 1968; Jenkins 1969; Tsuchiya 1969; Larter et al. 1970; Sisodia and McGinnis 1970*a, b;* Tsuchiya and Larter 1971).

The research program carried out by this group and their associates was initiated in 1954. The first material used was the hexaploid *durum* × rye amphidiploid produced by O'Mara. Several additional hexaploid triticales were developed from new crosses, and seeds of other existing wheat × rye amphidiploids, both hexaploid and octoploid, were collected. Many of the best triticale lines from all sources were intercrossed. In the Canadian program more improvements through selection were accomplished in hexaploid triticales than in the octoploids.

Important progress was made through the discovery of light-insensitive, early maturing types, and dwarf and semi-dwarf wheat lines, which were used as a source of shorter and stronger straw in the triticales. These characteristics (light-insensitivity, earliness, short straw, and disease resistance, particularly to stem rust) represented marked improvements over earlier hexaploid triticales. Parallel with the breeding work, quality evaluations of the grains were carried out, and it was also established that grain of the hexaploid triticales is suitable for use in cattle, sheep, and poultry rations. Since these triticales, which lack the D-genome, were not suitable for bread flour, they could instead fill the need for a feed crop in certain areas.

In 1969, one strain, Rosner, was licensed and became recognized as a new crop of commerce in Canada. Results from livestock-feeding experiments, distilling and brewing tests, and also from experimental manufacture of breakfast cereals indicated that triticale had considerable potential as a cereal crop.

A new and very important phase in the history of triticale was inaugurated less than 10 years ago when it was realized that hybridization between octoploid and hexaploid triticale may lead to quite valuable products of recombination. This was clearly realized by Pissarev about 1960 (*see* Pissarev 1966, p. 286–289); and in 1965, Kiss, in Hungary, demonstrated that secondary hexaploids derived from such crosses were superior to primary hexaploids (*see* Kiss 1966*a*, *b*). In the same year similar evidence was obtained in Winnipeg, Manitoba (Jenkins 1969).

Two secondary hexaploid Hungarian triticale varieties were officially registered a few years ago and have been more prolific in Hungarian state trials than any rye variety (Kiss 1971). In comparative trials with wheat, their value was equal to that of the wheat variety Bezostaya 1. Both the new triticale varieties are cultivated for fodder of grains or green matter and have given good results in feeding trials with mice, rats, poultry, and pigs. Baking trials have shown that hexaploid triticale flour may be successfully mixed to 50% with wheat flour. Even without admixture of wheat such triticale flour alone is reported to give excellent and tasteful brown bread. In 1969, about 40,000 acres in Hungary were under cultivation with hexaploid varieties of triticale.

The production of improved secondary hexaploids is now a standard technique used by all breeders of triticale, and Krolow (1969*a*, *b*) has worked out the cytological details occurring during this process. I hesitated to use this technique because so much genome-analytical work seemed to have proved definitely that the A and B genomes of tetraploid and hexaploid wheats were quite homologous or even identical. However, clear evidence that this is not the case was obtained from the University of Manitoba. By an elegant technique, Kerber (1964) succeeded in extracting the AABB part of bread wheat and found that these extracts were dwarf plants that differed in many ways from tetraploid wheat species, and were especially adapted to cooperate with the D-genome of *Aegilops squarrosa*. Later, Kaltsikes et al. (1969) carried out similar extractions.

Conclusion

At the workshop on triticale arranged by CIMMYT and IDRC in Mexico, we became vividly aware of the enormous amount of successful work on triticale that has been carried out here in Mexico by CIMMYT, particularly by Borlaug and Zillinsky.

The work started on a small scale in 1963 and was more firmly established in 1964 as a direct outgrowth of a cooperative breeding program between the University of Manitoba and CIMMYT. At that time a winter-breeding nursery involving most of the Canadian material was sown during November in Ciano. Following harvest, most of the material was returned to Canada for summer plantings, but part remained in Mexico to be sown at Toluca during May. From that time there has been a continuous free, two-way flow and exchange of triticale breeding materials between the Canadian and Mexican programs. Many other centres in the world have also become involved in this international work. In recent years this work has been carried out on a very large scale, and twice as fast as in countries limited to only one generation per year.

In this historical survey I have discussed only one special aspect of the Mexican work that has already been of very great importance and that will certainly have a strong influence on the future of triticale breeding: the origin of the Armadillo types and the block of favourable characters carried by them. In a recent paper by Zillinsky and Borlaug (1971) these characters were specified as follows: (1) a very high level of fertility, never before encountered in any triticale breeding program; (2) improved grain plumpness and test weight; (3) high grain yield per hectare; (4) insensitivity to daylength; (5) earliness; (6) one gene for dwarfness (semi-dwarf F_1); and (7) high nutritional quality.

Since it is highly probable that the Armadillos have arisen following a spontaneous cross to bread wheat, it seems likely that a whole block of linked genes has been incorporated into one of the chromosomes of hexaploid triticale or that a substitution of one or more chromosomes has occurred.

I know that Gustafson and Zillinsky (1973) have obtained evidence pointing in this direction and with the aid of quite new staining methods that make it possible to distinguish each rye chromosome in triticale, and probably soon also most or all of the wheat chromosomes, full clarity about the constitution of the Armadillo types can be expected (Merker 1973).

Thus, the rye genome in the Armadillos may have been weakened but favourably modified by the intrusion of one or more gene-blocks from wheat. If this process will go on still further, the name triticale for such material will become more and more dubious.

However, the species rye has already taken a revenge by invading one of the wheat genomes. In a series of five papers published during the period 1969–72 (Zeller 1969; Sastrosumarjo and Zeller 1970; Zeller and Fischbeck 1971; Zeller 1972; Zeller and Sastrosumarjo 1972), Zeller and his coworkers have demonstrated that rye chromosome No. V, which is known to carry several genes for disease resistance, is present in the commercial wheat variety "Zorba," where it has replaced wheat chromosome No. 1 **B**. The same thing has also happened in another German wheat variety, "Salzmünde Bartweizen." In a third wheat variety, "Weique," the situation is similar but more complicated. In one subline called "Weique Substitution" there is again the same substitution as in "Zorba" and "Salzmünde Bartweizen." In the other subline of Weique there is a translocation between wheat chromosome 1 **B** and rye chromosome V.

The very detailed analyses carried out by Zeller and his associates have also led to the detection of a number of other translocations. Thus, for instance, Zorba is homozygous for a specific translocation and the variety Holdfast for another translocation, involving chromosomes other than those in Zorba.

As is well known, much basic work with substitution and addition lines has already been carried out by many workers, especially Jenkins and Riley. However, as far as I know the recent cases in Germany are the first to demonstrate that such substitutions may arise spontaneously and are present in varieties that are economically prominent due to the presence of such substitutions.

Thus, we may now begin to wonder to what extent wheat varieties will absorb rye chromosomes and triticale varieties will absorb wheat chromosomes. There are probably certain limits to this kind of disorder, and until the ideal reshuffling of chromosomes and chromosome segments has been reached it will probably still be useful to retain the old-concept triticale.

Work with triticale is a wonderful experience and a splendid adventure. It is obvious that by continued interaction between intensive breeding work, basic cytogenetics, and several other sciences, we can really look forward to a future when this crop will become increasingly important for the welfare of mankind.

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Development of Triticales in Western Europe

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SANCHEZ-MONGE, E. 1974. Development of triticales in Western Europe, p. 31–39. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The pioneer work on triticale in Europe was done by A. Müntzing, who has been working with octoploid triticales since 1934. However, interest in Western Europe in triticales has been evident only since 1953, when a note on three new hexaploid triticales was presented at the 9th International Congress of Genetics.

Triticales obtained in Western Europe were produced by artificial doubling of the chromosome complement of the hybrid *Triticale* sp. × *Secale cereale*. Leim studied the genetical control of crossability between hexaploid wheat and rye and obtained evidence of two recessive genes, kr_1 and kr_2, controlling the high crossability.

In Sweden, the grafting of wheat embryos onto rye endosperm produced plants with increased crossability, although this was not duplicated in other parts of Western Europe.

Duplication of the chromosome number in the F_1 of wheat–rye hybrids has been accomplished by using colchicine applied in various ways. Embryo culture has been also used to increase the success of the crosses.

Breeding programs for the production of secondary triticales were started to use characteristics of the primary triticales, and low fertility and excessive seed shrivelling were partially overcome by selection within lines.

Recent results in breeding in Sweden, Switzerland, France, the United Kingdom, Denmark, and Spain are discussed, as well as the potential of triticale as an agricultural crop.

Résumé En Europe, les premiers travaux sur le triticale ont été faits par A. Müntzing qui travaille sur des triticales octoploïdes depuis 1934. Ce n'est cependant que depuis 1953 que l'Europe de l'Ouest a manifesté un intérèt pour cette céréale, lorsque fut présentée une communication sur trois nouveaux triticales hexaploïdes au Congrès International de Génétique.

Les triticales obtenus en Europe de l'Ouest ont été produits par doublement artificiel de l'ensemble chromosomique de l'hybride *Triticale* sp. × *Secale cereale*. Leim a étudié le moyen de commander génétiquement l'hybridation blé hexaploïde-seigle, et a obtenu la preuve que l'importance de cette dernière dépendait de deux gènes récessifs, kr_1 et kr_2.

Le greffage d'embryons de blé sur endosperme de seigle, effectué en Suède, a permis d'obtenir des plants plus facilement hybridables, mais cette expérience n'a été répétée nulle part ailleurs en Europe occidentale.

On est parvenu à doubler le nombre des chromosomes dans les F_1 d'hybrides blé × seigle en utilisant de la colchicine de différentes manières. La culture d'embryons a également été utilisée pour augmenter le succès des croisements.

Des programmes de sélection destinés à la production de triticales primaires, et la sélection au sein des lignées a permis de compenser partiellement la faiblesse de la fertilité et le ridage excessif des grains.

L'auteur expose les résultats des travaux de sélection récents entrepris en Suède, en Suisse, en France, au Royaume-Uni, au Danemark et en Espagne, ainsi que les possibilités du triticale sur le plan agricole.

In 1888 Rimpau discovered the first amphiploid between bread wheat and rye. The plant was probably a mixoploid chimaera arising from a 28-chromosome hybrid between *Triticum aestivum* and *Secale cereale*. The plant had a sector that spontaneously duplicated its chromosome number and produced 15 seeds, 12 of which gave rise to a uniform triticale while the other 3 resulted from pollination with wheat. Rimpau described this new cereal in 1891 and Müntzing (1939) confirmed that the somatic chromosome number of the Rimpau triticale was $2n = 56$.

The original concept behind the artificial production of triticales was to combine the bread-making quality and yielding ability of wheat with the vigour and hardiness of rye in a cereal that would have the ability to grow on poor, cold, dry soils. The new cereal can indeed, with special baking procedures, be used for bread making and produces a protein-rich bread. But the main use of triticale in future will probably be for animal feed, whether as grain, green forage, or silage.

The pioneer work on triticale in Europe was done by A. Müntzing, who has been working with octoploid triticales since 1934. But the interest in Western Europe on hexaploid triticale started after a note on three new hexaploid triticales (Sanchez-Monge and Tijo 1953) was presented at the 9th International Congress of Genetics in Bellagio, Italy, in 1953. The idea of working intensively at the hexaploid level in triticale was suggested to us by C. A. Jørgensen when we were examining the large collection of tetraploid wheat genotypes from Spain.

Production of Triticale

The triticales that we designate as "primaries" were obtained in Western Europe by the artificial doubling of the chromosome complement of the hybrid "*Triticum* sp. × *Secale cereale*." The crosses between tetra- and hexaploid species of wheat and diploid rye were more easily made by using the wheat species as the mother plant. The intergeneric cross is more easily made with hexaploid than with tetraploid wheats.

At both levels of ploidy, different wheat genotypes show different ability to set seed when pollinated with rye pollen. Some experiments have shown no influence of the rye genotype on the crossability (Krolow 1964). However, the utilization of alloplasmic rye with wheat cytoplasm seems to increase the percentage of germinable seeds in the cross *T. aestivum* × *Secale cereale* (Vettel 1961).

In a study made by Lein (1943) on the genetical control of crossability between hexaploid wheat and rye, evidence was obtained of the existence of two recessive genes, kr_1 and kr_2, controlling the high crossability. The dominant Kr_1 reduced crossability to a greater degree than did Kr_2. The location of these two loci in the wheat genome was investigated by Riley and Chapman (1967). They located Kr_1 on chromosome 5B and Kr_2 on chromosome 5A.

Several attempts have been made to increase the crossability of wheat and rye. The grafting of wheat embryos onto rye endosperm produced plants with increased crossability according to results obtained in Sweden (Müntzing 1956). In other countries in Western Europe no increase in crossability was obtained using this technique with hexaploid (Krolow 1964; Derenne 1960) or tetraploid wheats (Sanchez-Monge 1956*a*). The heterozygosity of the tetraploid wheat mother plant did not increase the crossability in other experiments (Sanchez-Monge 1956*a*).

With tetraploid wheats the percentage crossability average seed set obtained by Krolow

(1970) was 13.36% and the percentage of germinated seed in pollinated flowers was 0.15%. In the same experiment the corresponding value to the last figure for hexaploid wheat was 3.07%. My own results with 64 genotypes of tetraploid wheat were 0.6% average seed set and 0.4% seed germination in pollinated flowers (Sanchez-Monge 1956*a*, *b*). The inbreeding and selection of self-fertile lines of rye to be used as pollen parents with tetraploid rye did not have any influence on crossability (Sanchez-Monge 1956*a*).

The duplication of the chromosome number in the F_1 of wheat–rye hybrids has been accomplished by using colchicine applied in different ways:

— coleoptile immersion in the colchicine solution (Müntzing 1939);

— alternative immersion of the washed roots of plants at the tillering stage in weak solutions of colchicine (0.05%) and tap water; the plants were usually put in the colchicine solution during the day and in tap water during the night and the treatment lasted for 4 days (Villax et al. 1954; Villax 1957; Wellensiek 1947);

— the cutting back of a couple of tillers and application of the colchicine solution to them with the use of small vials (Bell 1950; Sanchez-Monge 1956*a*; Linde-Laursen 1973) or hydrophilous cotton protected with polyethylene (Cauderon and Saigne 1961).

Embryo culture has been also used to increase the success of the crosses (Lupton et al. 1973).

Breeding

Research workers soon realized that the primary triticales were autogamous and vigorous, but they were partially sterile and the kernels were shrivelled. The first six lines of the octoploid triticale that Müntzing (1939) studied showed variability for characters such as vigour, pollen fertility, seed setting, grain shrivelling, baking quality, and winterhardiness. This variability was quickly used by breeders, who made crosses between the primary triticales and started breeding programs for the production of secondary triticales.

The inconveniences of low fertility and excessive seed shrivelling were partially overcome by selection within lines. However, the results were slow in coming and sometimes contradictory. Müntzing (1972), Ingold et al. (1968), and I (Sanchez-Monge 1969) obtained favourable results, whereas Aufhammer et al. (1961) and others did not find that the selection of plants with the highest seed set was effective.

A much debated question that arose from the production of secondary triticales was that of the relationships between fertility, aneuploidy, and the regularity of the meiosis. Vettel (1960), working with the Rimpau triticale and several mutants, found a negative correlation between the frequency of aneuploid descendants and the fertility of the mother plant. Pieritz (1966) obtained similar results and also showed that aneuploidy is mainly transmitted through the female gamete. Pollen grains with aneuploid numbers rarely functioned and when they did so, the chromosome number only deviated by ±1 chromosome from the euploid number.

Working with octoploid material showing very high chromosomal instability, Krolow (1962) was able to reduce the aneuploid frequency from 83.3% to only 60.6% by selecting the more fertile plants. Reselection within lines allowed him to reduce the aneuploid frequency to 40.3%. In the same experiment, Krolow found a positive correlation between aneuploid frequency and sterility of the mother plant and between aneuploidy and reduction of tallness. Later experiments (Krolow 1963) confirmed these results.

At the hexaploid level, Krolow (1966) found much lower figures for the frequency of aneuploidy. In the progeny of euploid plants with 42 chromosomes he found 7% aneuploids, mainly with 41 and 43 chromosomes. The progenies of these aneuploids showed a tendency to revert to the euploid number of 42, as the average chromosome number in the progeny of 41-chromosome plants was 41.31, and 42.53 in the progeny of 43-chromosome plants. However, it is easy to show, using Krolow's figures, that in the absence of selection the total frequency of aneuploids tends to increase in such a population.

In crosses between hexaploid triticales it was possible to select, in the F_3 generation, plants with good fertility, 42 chromosomes, and a more stable meiosis than the parents of the cross (Krolow 1969).

It was suggested by Müntzing (1956) that some of the unfavourable characters of triticale could be due to the fact that it is an autogamous species resulting from the integration of the genotype of an autogamous wheat species with the genotype of an allogamous rye species. The genetic contribution of rye would be subject to inbreeding degeneration. He then suggested that inbred lines of rye selected for self-fertility or F_1 hybrids between them be used for the production of triticales.

The results with my own material (Sanchez-Monge 1969), in which high levels of fertility were quickly reached, could be due to the use of self-fertile lines of inbred rye. It is worth mentioning here that the highest values of self-fertility in inbred rye have been obtained from populations coming from the southeastern region of Spain where the wild species *Secale montanum* is also found. It is possible that genes of this later species were introgressed into the cultivated rye.

The work of Riley and Chapman (1957) gives some support to the ideas of Müntzing. Three artificial allooctoploids obtained from *Triticum aestivum* × *Secale cereale*, *T. aestivum* × *Aegilops longissima*, and *T. aestivum* × *Aegilops caudata*, were compared by Riley and Chapman.

The breeding systems of the four species are: *T. aestivum* = self-compatible and autogamous; *Ae. longissima* = self-compatible and usually autogamous; *Ae. caudata* = self-compatible and allogamous; *S. cereale* = self-incompatible and allogamous.

The fertility was highest in the octoploid involving *Ae. longissima* and lowest in the one involving *S. cereale*. The authors suggested that the fertility of an alloploid can be affected by the interaction of the breeding systems of the parental species.

The production of secondary triticales from crosses between primaries has been frequently used in Western Europe both at the octoploid (Müntzing 1939, 1956, 1963, 1972; Ingold et al. 1968; Cauderon 1970) and at the hexaploid levels (Sanchez-Monge 1969; Lupton et al. 1973).

Handling crosses between octoploid triticales has been found to be more difficult than with wheat (Müntzing 1939). The F_1 shows heterosis but in many instances is lower in seed setting and has more irregular meiosis than its parents. Aufhammer et al. (1961) found that the fertility of the progenies was dependent on that of the parents and also on their specific combining ability. In crosses between my hexaploid triticales I have not found any such reductions of seed set in the F_1 in comparison with the parental seed set.

Secondary octoploid triticales are also being produced from other types of crosses. Ingold et al. (1968) have obtained secondary octoploids by pollinating the F_1 of *T. aestivum* × *S. cereale* with pollen of other octoploid triticales. Some 56 chromosome plants were obtained in this backcross and still more in successive backcrosses. This type of cross has been also used by Vettel (1961) in the production of secondary triticales.

Secondary hexaploid triticales have been recovered from the segregating progenies of the cross between octoploid and hexaploid triticale, the cross being more easily made when the octoploid is the mother plant (Cauderon 1970; Müntzing 1972). Octoploids can also be recovered from this cross, but for this it is better to use the backcross of the F_1 to octoploid triticale, instead of raising the F_2.

The fact that good types of secondary hexaploids have been obtained from the octoploid × hexaploid crosses could be due to the existence of differences between the A and B genomes of tetraploid wheats and the same genomes of hexaploid wheats. The cross octoploid × hexaploid triticale gives opportunity for recombination between the chromosomes of these genomes, and some recombinants may give a better triticale genotype (Müntzing 1972).

In the program of triticale breeding at our Institute we have been using crosses between hexaploid triticale and bread wheat and more recently crosses between hexaploid triticale and durum wheat.

Another interesting approach to the breeding of triticale is the use of induced mutations. By treatment of the seeds with X-rays at a dosage of 16 kr, Vettel (1960) obtained 5.48% mutants in the X_2 progenies. The more frequent types of visible mutations were those of "compact ears" and "lax speltoid ears." Some mutants with improved seed quality were also obtained.

For the improvement of endosperm quality we also started an irradiation program with the assumption that seed shrivelling in hexaploid triticale could be due to an interaction between the cytoplasm (plasmagenes) of wheat and the rye chromosomes, and that a destruction or mutation of the wheat plasmagenes responsible for the unfavourable interaction through irradiation could result in the improvement of the endosperm quality. Potted plants of triticale were emasculated and immediately irradiated in a gamma field with 1500–3000 r. After irradiation the emasculated ears were pollinated using pollen of sister plants of the same triticale line. Five back-cross progenies were recovered with smoother endosperm and the character showed maternal influence in its inheritance (Sanchez-Monge 1968).

The production of decaploid and tetraploid triticales has also been attempted. The decaploid was obtained by Müntzing (1956) by crossing octoploid triticale with rye and doubling the chromosomes of the 35-chromosome F_1. The resulting decaploid triticale was very unstable, lacked vigour and fertility, and showed a tendency to revert to lower chromosome numbers.

Tetraploid triticales were obtained by Krolow (1973) in the selfed progenies of the cross between hexaploid triticale and rye. In the fifth selfed generation, 97% of plants had 28 chromosomes. These tetraploid triticales have seven pairs of rye chromosomes and the other seven pairs can be a combination of chromosomes of the genomes A and B. The interesting material obtained by Dr Krolow will be evaluated in the near future.

Another possibility that we must explore in the breeding of triticale is that of the production of hybrid seed by means of the use of cytoplasmic male sterility. It is likely that triticale is more suitable material than wheat for hybrid seed production because pollen production is more abundant and the sterile flowers remain more open for a longer time in triticale than in wheat. The experiments of D'Souza (1972) showed that rye, triticale, and secalotricum (triticale with rye cytoplasm) have bigger stigmas than wheat and longer stigma receptivity. In unfavourable conditions of high temperature and low relative humidity the reduction in the duration of stigma receptivity was less drastic in triticale than in wheat.

The transference of triticale chromosomes to different male-sterilizing cytoplasms has been through back-crosses, using as female parents alloplasmic hexaploid and tetraploid wheats with the cytoplasms of *Aegilops ovata, Ae. caudata,* and *Triticum Timopheevi.* For the production of hexaploid triticale with rye cytoplasm, a variety of tetraploid rye was used as female parent (Table 1). No triticale line with rye cytoplasm has yet been obtained that breeds true for male-sterility. Some fertile lines with rye cytoplasm do not compare favourably with their counterparts with wheat cytoplasm (Table 2). The cytoplasms of *Ae. ovata, Ae. caudata,* and *T. Timopheevi* are strongly male-sterilizing as far as the hexaploid triticales in our first trials are concerned, and could be used for hybrid seed production if satisfactory restorers can be found. The cytoplasm of *Ae. caudata* is probably the least useful because lower seed set values are always obtained.

Octoploid triticales with rye cytoplasm (secalotricum) compared with the ones obtained in reciprocal crosses by Smutkupt (1968) who found longer ears and culms with rye cytoplasm, but did not consider the identity of the nuclear genotype in the compared lines.

Some Results and Actual Problems

The Swedish octoploid triticales produced by Prof Müntzing and coworkers (Müntzing 1972) have reached yields closely approximating those of the hexaploid wheats used for comparison. The bigger kernels of triticale

TABLE 1. Types of substitution backcrosses.[a]

Secale cereale 4*n* × Triticale^{b} ($b = 7$)
(*Aegilops ovata* × *Triticum aestivum*^{b}) × Triticale$^{b'}$ ($b = 11$, $b' = 6$)
[(*Ae. ovata* × *T. dicoccum*^{b}) × *T. turgidum*$^{b'}$] × Triticale$^{b''}$ ($b = 8$, $b' = 4$, $b'' = 2$)
(*Ae. caudata* × *T. aestivum*^{b}) × *Triticale*$^{b'}$ ($b = 12$, $b' = 4$)
[(*Ae. caudata* × *T. aestivum*^{b}) × *T. turgidum*$^{b'}$] × Triticale$^{b''}$ ($b = 7$, $b' = 4$, $b'' = 2$)
(*T. timopheevi* × *T. aestivum*^{b}) × Triticale$^{b'}$ ($b = 16$, $b' = 4$)
(*T. timopheevi* × *T. turgidum*^{b}) × Triticale$^{b'}$ ($b = 12$, $b' = 3$)

[a] b, b', and b'' are the number of backcrosses in the material of INIA.

TABLE 2. Comparison for agronomic characters between triticale lines with wheat and rye cytoplasm.

Character	Wheat vs. rye cytoplasm: Line JM-130	Wheat vs. rye cytoplasm: Line JM-135
Plant height	5% higher*	4% higher*
Tillering	32% higher*	21% higher*
Maturity date	Identical	Identical
Ears/plant	56% higher**	39% higher**
Spikelets/ear	5.5% higher*	0.9% higher
Flower fertility	2.9% lower	5.8% higher
1000 kernels weight	10.7% lower**	3.2% lower*
Kernel protein content	8.4% higher*	6.3% lower
Grain yield per ha	42.8% higher*	43.6% higher*
Protein per ha	54.8% higher	34.6% higher

*Significant at the 5% level.
**Significant at the 1% level.

compensate for the lower seed setting. The seed quality of some lines is also as good as in the wheats and the crude protein content is always higher in triticale than in wheat.

In Switzerland Ingold et al. (1968) obtained triticale lines with yields 78.3% that of wheat.

Cauderon (1970) reported that in France triticale could become a good cereal for feed grain production either as a winter- or a spring-sown crop, if the problem of lodging could be solved. Yield trials in 1970 with material of Canadian origin showed that triticale gave the same productivity as "Moisson" wheat even with heavy lodging of the triticale plots. Chemical analysis of several lines gave crude protein contents between 17.4 and 22.1% with a lysine content of 2.6–2.9 g per 100 g of protein.

In the United Kingdom the breeding program for triticale at the Cambridge Plant Breeding Institute was started only 3 years ago (Lupton et al. 1973). The program is aimed to the production of secondary hexaploid triticales by intercrossing their own primary types and also crossing them with other hexaploids from CIMMYT and other origins. Their main problems are winter-hardiness, resistance to ergot, yellow rust, powdery mildew, and glume blotch. They hope to preserve in their material the resistance of rye to take-all and eyespot. Resistance to ear sprouting is also a primary need.

In Denmark Linde-Laursen (1973) has been using octoploid triticales to transfer to wheat the resistance of rye to *Gaenmannomyces graminis* and to powdery mildew. A limited number of farmers have been growing hexaploid triticale lines of Canadian origin but the yields were inferior to those of other cereals. Lodging in these triticale lines was also a problem.

In Spain we have released the hexaploid triticale variety "Cachirulo" and several seed-producing private companies have been buying 12–16 tons of foundation seed from us over the last years. It is difficult, however, to give an estimate of the acreage planted in our country because the seed companies keep the figures of seed multiplication and sales to themselves. With the variety Cachirulo we have no disease problems, although 2 years ago we did detect a small infection with ergot in one field near Madrid. Our variety Cachirulo is, however, far from perfect. It is too tall and can become lodged in rainy years. Also it is a little difficult to thresh. As good attributes we can mention its high fertility and the high protein content of its kernels. The figures obtained by chemical analysis fluctuate between 16 and 25.2% protein depending on maturation conditions, soil type, and fertilization. The average of many trials all over Spain is 20%. The lysine content per 100 g of protein was 3.75 g for a sample with 18.4% protein and 3 g for another with 20.1% protein.

Our present program aims at a reduction in height without loss of fertility, protein, or disease resistance, and also an improvement in the ease of threshing. As donors for short culm character, we have been using a recombination of two different mutants: one obtained after irradiation in our own material, and the other isolated in a segregating population that was sent to us by Prof B. C. Jenkins. The material received from CIMMYT has been also used in the last 2 years.

Utilization

I am convinced that triticale has a great future as an agricultural crop. It can be used in different ways, but seems specially useful for the production of grain for animal feeding. Two years ago we sent samples of 0.5 kg to more than 400 factories that make animal feeds, and that were distributed all over Spain, asking them to make their own chemical analysis and give an opinion. This was unanimously favourable and they are interested in the use of this cereal and in the manufacture of animal feeds. It two cases the people in the factories did not read the circular letter accompanying the sample carefully and as a result we received orders for several thousand quintals of the crop.

Some experiments have been also carried out at our Institute regarding the utilization of triticale. In one experiment on the feeding of meat poultry (Carballo et al. 1970), based on making isocaloric and isoproteic rations, it appeared that it was possible to use triticale to replace high protein corn in the diet.

Triticale can be used for bread making if special techniques are used and if a protein-rich bread is desired. In another experiment at our institute (Garcia-Olmedo et al. 1970) different products from triticale grain were obtained by experimental milling. The variety used was Cachirulo with 20.8% protein. One of the fractions of shorts obtained (23.9% of the total) contained 25.4% protein. The Buhler flour (63.0%) contained 18.3% protein and by mixing 20% of this flour with 80% of the standard flour used in the bread factories of Madrid, the quality of the bread and, of course, its protein content were highly improved.

Triticale can be used also for silage and the preliminary experiments we have made have given a good product. It can also be used as green forage, as some experiments at the Cambridge Plant Breeding Institute (Rogers and Webb 1972) have shown. In 1971 they obtained 19.4 tons per hectare of dry matter containing 37.5% soluble carbohydrates with a digestibility of 56.5%.

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Triticale-Breeding Experiments in Eastern Europe

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Kiss, Á. 1974. Triticale-breeding experiments in Eastern Europe, p. 41–50. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Breeding of wheat–rye hybrids was first reported in 1891 by the German plant breeder W. Rimpau. His octoploid "Triticale Rimpau" is still cultivated in Germany in numerous locations in experimental plots, although at present triticale research in the German Democratic Republic is not considerable.

In Czechoslovakia, intensive research work on triticales has been done since 1970 at various research institutes.

Trials have begun in Poland with octoploid triticales and recently with hexaploid hybrids. The Institute of Plant Breeding at Lublin is the coordinating centre of the work. Extensive research as well as comparison trials are being carried out at other locations.

Bulgaria also began its testing with octoploid triticales and since 1970 has studied hexaploid triticales; it is also engaged in breeding research.

In Rumania, foreign varieties from Canada, Mexico, the USA, and Hungary are being crossed. Amylase activity is being studied in Bucuresti and crossing trials are being carried out at Fundulea and Cluj.

Wheat–rye cross trials began in Hungary in 1917. Constant hexaploid hybrids were first produced in 1950. In 1960 the secondary hexaploid hybrid, Triticale No. 30, was tested in large-scale farm conditions. Triticale No. 57 and Triticale No. 64 were first released in 1968. They are rather tall and can only compete with rye on good sandy soil. At present dwarf (A_3), semi-dwarf (A_2), and short (A_1) hexaploid triticales are bred for wheat soils. There are still many problems to solve for them to be competitive with intensive wheat varieties. The variety "Bókoló" looks very promising. Cooperation has been established between research workers in Poland, Czechoslovakia, and Bulgaria.

Résumé C'est en 1891 qu'un phytosélectionneur allemand, W. Rimpau, a signalé la première obtention d'un hybride blé-seigle. Son "Triticale Rimpau" octoploïde est toujours cultivé en parcelles expérimentales dans de nombreux endroits en Allemagne, bien qu'à l'heure actuelle les recherches sur le triticale n'aient pas une grande ampleur en République Démocratique Allemande.

En Tchécoslovaquie par contre, les travaux de recherche sur le triticale ont été poursuivis d'une façon intensive depuis 1970 dans différents instituts de recherche.

En Pologne, les essais ont commencé avec des triticales octoploïdes puis, plus récemment, avec des hybrides hexaploïdes. L'institut de Phytosélection de Lublin y

joue le rôle de centre coordonnateur. Des recherches poussées et des essais comparatifs sont en cours en d'autres endroits.

Le programme d'essais de la Bulgarie a également commencé avec des triticales octoploïdes, puis avec des variétés hexaploïdes depuis 1970; ce pays effectue également des recherches génétiques.

La Roumanie procède à des croisements de variétés importées du Canada, du Mexique, des Etats-Unis et de Hongrie. L'activité de l'amylase est étudiée à Bucarest et les essais de croisement sont effectués à Fundulea et à Cluj.

En Hongrie, les essais de croisement blé-seigle ont débuté en 1917. C'est en 1950 qu'y furent produits les premiers hybrides hexaploïdes héréditairement constants. En 1960, l'hybride hexaploïde secondaire Triticale 30 a fait l'objet d'essai en plein champ sur une grande échelle. C'est en 1968 que furent diffusés pour la première fois les Triticales 57 et 64. Ils ont une paille plutôt grande et ne peuvent remplacer le seigle que dans les bons sols sableux. On sélectionne actuellement des hexaploïdes nains (A_3), demi-nains (A_2) et courts (A_1) pour les terres à blé. Il reste encore de nombreux problèmes à résoudre avant qu'ils puissent être concurrentiels par rapport aux variétés de blé de culture intensive. La variété "Bókoló" semble très prometteuse. Une collaboration s'est instaurée les chercheurs Polonais, Tchèques et Bulgares.

RESEARCH WORK on triticale breeding in eastern Europe began in Germany. Rimpau (1891) reported in detail on artificial crosses between wheat and rye. He mentioned A. S. Wilson's two sterile hybrids obtained by crossing wheat and rye and presented at the Botanical Society of Edinburgh on 31 May 1875. He also referred to an article in the *Deutsche Landwirtschaftliche Press* on Rümker's obtaining 10 wheat–rye hybrid grains in 1882–83, nine of which germinated, eight of which survived. Rümker succeeded in growing progenies of the eight plants and found some rye characteristics, but he got only a few grains "die anscheinend keimungsfähig und wertlos waren." In the summer of 1885, 17 shrunken grains were found in 14 hybrid ears. He grew 15 plants of them "ihre Aehren waren Weizenähren und ähnelten doch ausgesprochen jenen des Roggens; die Pflanzen waren durchschnittlich 3 Fuss 5 Zoll hoch, die höchste mass 4 Fuss." The plants later turned to wheat.

Rimpau began his trials with wheat–rye crosses in 1888 with varieties of sächsischer roter Landweizen and Schlanstedter Roggen. He grew the four hybrid grains he obtained in pots in a glass house in 1889. Three of them fully resembled the mother plant; the fourth was 30 cm taller than the wheat parent with narrow, long ears, transitory habit, but coming nearer to the wheat. The flowers were open for several days. He obtained 15 partly shrivelled, partly full grains.

In 1890 the 15 grains were sown in pots and grown in a glass house. After overwintering they were transplanted to field plots: 1 plant had completely sterile ears of brown Squarehead shape; 2 plants had fertile ears of white Squarehead shape; and 12 plants had long, narrow, red-brown ears, rather like wheat, and poorly fertile.

He harvested 125 ears, many of which were completely sterile. In the most fertile one he found 55 shrivelled grains. Grain mean number per ear was 15.8. Progenies of these hybrids are still found in the nursery gardens of triticale researchers.

They are also found in Halle at the Agricultural Faculty of Martin Luther University, in Berlin at the Faculty of Genetics of Humboldt University, in the research institutes of Quedlinburg, Gatersleben, and Gülzow-Güstrow, indicating that research work on triticale is still going on in East Germany, although on a smaller scale.

East Germany

Plant Breeding Institute, Quedlinburg

Cytogenetics of octoploid and hexaploid triticales are being studied by Drs K. Skiebe and G. Senf. In octoploid × hexaploid and reciprocal hybrids, the optimal polyploid level is being studied. They want to produce male-sterile triticales; their work is still in the very early stages.

Plant Breeding Institute, Gülzow-Güstrow

Dr Gisela Szigat maintains a variety assortment of octoploid and hexaploid triticales, carrying out plant development and yield analysis tests (personal communication 1973). According to present data, hexaploids are more fertile than octoploids, although types of the latter have higher quality and better frost hardiness. In drill-sown comparison trials of the Hungarian Triticale No. 64, it failed to reach the fertility level of rye. In large-scale growing, the winter-hardiness of triticales is poor.

Humboldt-Universität, Berlin, Sektion Genetik

Prof Dr U. Nürnberg is engaged in limited cytogenetic analyses of the Hungarian hexaploid triticales.

Martin-Luther-Universität, Halle, Sektion Pflanzenzüchtung

Prof Dr H. Schmalz has carried out comparison trials with new dwarf and semi-dwarf Hungarian hexaploid triticale strains, as well as with short and semi-dwarf winter wheat varieties (personal communication 1972). According to tests, the semi-dwarf triticale Bókoló and the three-level strains can compete in culm strength and fertility with wheats in the district of Halle. The fertility of dwarf triticales is satisfactory. Grain quality and test weight remain, however, to be improved. Dr D. Mettin is also involved with cytogenetic studies to a limited extent.

Intitut für Kulturpflanzenforschung, Gatersleben, Kreis Aschersleben

Dr Chr. Lehmann is investigating numerous octoploid and hexaploid triticales in his assortment of cereals collected from around the world.

Universität Rostock, Sektion Tierproduktion

Dr Habil W. Wiesenmüller has been studying the performance of Triticale No. 64 in feeding and nutrition trials (personal communication 1971). Results are promising. He especially emphasizes the high lysine content and protein efficiency ratio of triticales.

In East Germany no breeding work is being done. New Hungarian and foreign hybrids are being tested to find suitable types for certain regions. They want varieties with better culm strength than that of the present Triticale No. 64.

Czechoslovakia

Intensive research has been in going on in Czechoslovakia since 1970.

Vyskumny ustav rastlinnej vyroby, Piestany, okv. Trnava

Dr L. Riman, CSc., coordinator of the triticale research program, oversees a large amount of research on genetics, variety comparison, yield analysis, and plant development physiology. He also maintains relations with the Hungarian research team. Dr J. Zatko deals with culturing methods of wheat and triticale. In the autumn of 1973 comparison trials with the Hungarian triticale Bókoló and some intensive wheat varieties were set up.

Ustav genetiky a slachtenia, Praha 6 – Ruzyne 507

Dr A. Kovacik is working on genetics and Dr E. Stuchliková on cytogenetics of numerous foreign, Mogileva, and Hungarian hexaploid triticales. Optimal polyploid level and correlation between anomalies in meiosis and fertility are being studied.

Slachtitel'ska stanica, Uhretice, okv. Chrudim

Dr V. I. Mogileva, V. E. Pissarev's pupil, has developed frost-hard and fertile hexaploid triticales (Mogileva 1972). Because they are rather tall, she recently used Hungarian short strains in her cross trials. She hopes to develop valuable short hexaploid hybrids within a short time. At present she is analyzing F_3 and F_4 generations.

Slachtitel'ska stanica, Králová pri Senci, okv. Galanta

Breeding hexaploid triticales is being carried out by F. Caputa (1972). Crosses with Hungarian dwarf triticales were recently made and F_3 and F_4 generations are being studied.

Vysoká skola pol'nohospodárska, Nitra

Dr Prof A. Frideczky (1972) and Dr Z. Gromová are studying agricultural methods of triticale and wheat yields. The Triticale No. 64 cannot compete with wheats of strong straw on good soils. Maximum yield on erect or slightly lodged stock was about 45–50 q/ha. Wheats of good yield potential reach 60–70 q/ha.

Vyzkumny ustav mlynársko – pekarsky, Praha-Pankrác

Dr J. Kalina is studying milling and baking characteristics of triticale. According to trials, triticale produces good bread. The amylase activity is high, and the bread is tasty, and has rye characteristics.

Slachtitel'ska stanica, Branisovice, okv. Znojmo

Drs M. Procházka and V. Kulich are performing quality tests, and have found the protein content of triticale to be 1–3% higher than that of wheat varieties. The feeding trials with pigs and poultry they are carrying out are especially promising.

Ing. M. Kovar (1972) has carried out fertility studies of hexaploid triticales and intensive wheats at eight research stations. In the trials in 1972, Triticale No. 64 performed well, with surprisingly high yields (50.9–81.5 q/ha) as compared with the wheat variety Kavkaz (60.8–77.2 q/ha). On plots treated with CCC, Triticale No. 64 gave 69.2 q/ha and Kavkaz 67.1 q/ha grain yield. In Czechoslovakia very intensive triticale research is going on. At present, intensive wheat varieties are more fertile and have better adaptability than triticales. However, if triticale does not lodge, yields as large as or even larger than the wheat Kavkaz can be expected.

Cooperation between Czechoslovakia and Hungary with regard to triticale research is good. We hope to report better results in the years to come.

The activities of Dr L. Riman and Ing. J. Bodian deserve special mention. Under the auspices of the Slovakian Academy they organized the "First Congress of Triticale Breeding and Growing" in Piestany, Czechoslovakia, 4 July 1972 (Riman 1972). Besides the principal lecture, 21 other papers dealt with the present state and problems of triticale research. The Hungarian Triticale No. 64 is grown on about 2000 ha, and yields are variable.

Poland

Pioneers of triticale research in Poland are Prof Drs C. Tarkowski, J. Korohoda, and Slabonski. Initially, only octoploids were developed; however, after Dr M. Jagielski's visit to Hungary in 1968, trials began with hexaploids as well.

Institute of Plant Breeding, Lublin

Prof Dr C. Tarkowski deals with cytogenetic, breeding, and culturing problems (personal communication 1973). Since 1969 he has been coordinator of the Polish triticale research and he has been co-operating with the Hungarian triticale research team since 1970. The aim is to develop suitable triticale forms to withstand Polish and Hungarian conditions. The hard Polish winter requires selection of winter-hardy, hexaploid varieties. The Poles have joined the Mexican ITYN experiments and are attempting to develop winter- and spring-type hexaploid triticales. They want to incorporate dwarfness from Hungarian triticales. Tarkowski is also analyzing monosomes as well as cytoplasm effects. He succeeded in developing a tetraploid triticale, which presently is only of theoretical interest. According to his studies, the cytological stability of the Hungarian strain Bókoló A_2 is very good. Octoploids of Prof Dr J. Korohoda are used as cross partners in several countries. G. Stefanowska, cytogeneticist, is analyzing chromosome karyotypes. She used the Hungarian A_3 and A_2 strains in her numerous crosses.

Institut Hodowli i All. Roslin, Warszawa

Dr S. Nalepa, a plant breeder, is working with Polish, Hungarian, Swedish, American, and Mexican material.

Katedra Hodowli Roslin, Szczecin

Prof Dr A. Slabonski is crossing octoploid and hexaploid triticales.

Copernicus University Centre of Applied Biology

Dr A. Chrominski has been carrying out variety trials.

Stacija Hodowli Roslin, Laski

Mgr. E. Tymieniecka is engaged in triticale breeding under the direction of Dr T. Wolski, who is a wheat and rye breeder. Comparison trials have been set up with Polish, Swedish, American, Mexican, and Hungarian triticales, which offer a considerable assortment of varieties. Dr J. Brykczynski is studying winterhardiness in triticales. Pissarev's octoploid AD 72 was the most frost-hardy. The dwarf and semi-dwarf Hungarian triticales were less frost-hardy by 20–30%.

Institute of Genetics, Poznan

Dr T. Chmielenski is engaged in fertility studies of octoploid and hexaploid triticales, and also the causes of sterility.

Stacija Hodowli Roslin, Jeleniec

Dr Kalina Komenda grew A_2 and A_3 types of hexaploid triticales of Hungarian origin on particularly poor sandy soil. Large plot variety comparison trials were performed with wheat, rye, Triticale No. 64, and Triticale No. 57. The highest yield was obtained in rye, followed by triticale. Wheat varieties did not perform well. On about 1 million ha of sandy soil with pH 4–5, wheats were quite unsuccessful. It is hoped that triticale will grow well in these soil conditions. The cytogenetic and genetic research work of Polish workers is also considerable. In 1970–73, Hungarian triticales were compared and selected on seven locations. Results are promising but not entirely satisfactory. To a lesser extent breeding work is also done and culturing methods are tested. Triticale No. 64 is grown on about 1000 ha.

Institut Uprawy Nawozenia i Gleboznawstwa, Pul'awy

Dr J. Mazurek, Jan Mazurek, and K. Jaworska are engaged in comparison trials with triticale, wheat, and rye, and yield analyses. In their scheduled sowing date trials, Triticale No. 64 was able to compete with wheat and rye. Dr E. Nowacki, assistant professor, is performing physiological and quality tests.

Short and semi-dwarf triticales of Hungarian origin are also compared at the Plant Breeding Stations at Polanowice, Borek (near Krakow), Sobiejnchy, and Pisanica.

Bulgaria

Triticale breeding, genetic and agricultural trials are being conducted in several research institutes under the leadership of Prof Dr Pavel Popov (1971), academician and wheat breeder, Sofia. Dr Popov and Dr S. M. Tsvetkov (a fellow research worker) are in frequent contact with the Hungarian team.

Wheat and Sunflower Research Institute, General Toshevo

Besides being engaged in wheat breeding, Dr S. M. Tsvetkov also works in the breeding of hexaploid triticales. From crosses of Hungarian dwarf and semi-dwarf triticales he has obtained very varied selections. His cytogenetic studies and developments of secondary hexaploid triticales are also of interest.

High Agricultural Institute "V. Kolarov," Plovdiv

Prof Dr I. Kolev is chiefly engaged in developing and breeding octoploid triticales and studying their genetics. His amphiploids of Bezostaya wheat and rye are important. He recently produced hexaploid triticales and secondary hexaploids from octoploid and hexaploid hybrids.

Institute of Genetics and Plant Breeding, Sofia

Dr R. J. Baeva is developing octoploid and hexaploid triticales as well as secondary hexaploids. She succeeded in developing some fertile types using Hungarian short triticales. Cytological studies and meiosis analyses are also being done. Her endeavours to eliminate sterility deserve mention.

Plant Breeding Station, Sadovo

Dr D. B. Bojadzsieva deals with octoploid and hexaploid triticales and comparison trials. In Bulgaria, Triticale No. 64 is grown on experimental large plots. However, it lodges easily. They want to grow short and semi-dwarf types for fodder when they are competitive with wheat.

Rumania

Cereal Research Institute, Fundulea

Prof Dr N. Ceapoiu, director of the Cereal Research Institute in Fundulea is studying meiosis and mitosis phenomena in octoploid triticales. He is trying to develop hexaploid forms by crossing CIMMYT, Canadian, Californian, and Hungarian triticales. According to him there is no type suitable for pure agricultural trials.

Central de Cerletari Biologice, Cluj

Dr M. Alpar is producing wheat–rye crosses to a limited extent.

Institute Biologie lab. Genetica Vegetala, Bucuresti

Dr M. Elias is engaged in quality tests, and is especially interested in amylase activity and amylase components.

The Hungarian Triticale No. 64 has been grown on 400 ha with varying results for 2 years. The variety tends to lodge and does not develop high fertility.

Hungary

Since E. Obermayer's work in 1917 in the Plant Breeding Research Institute of Mosonmagyaróvár, wheat–rye hybridizations have been attempted almost yearly. B. Györffy in 1948, and Gy. Rédei and Á. Kiss in 1949 developed sterile polyhaploid hybrids. In 1950, with the cross *T. turgidum* × *S. cereale* (Magyaróvári rozs) the first primary hexaploid triticale was produced. In 1952, from crosses of *Triticum aestivum* F 481 × *S. cereale* and B 1201 × *S. cereale*, octoploid triticales were obtained. Hexaploid and octoploid triticales were first crossed in 1954. The secondary hexaploid hybrid, Triticale No. 30, was obtained from this progeny in 1960. It was grown on several farms in sandy soil but its culture never extended because of its weak culm.

Between 1954 and 1956, an F_3 population was grown from multiple octoploid triticale crosses (T. AD 20/1, T. Taylor, T. Meister, T. Rimpau) and from the cross of selected F_2 elites (8x) and Triticale No. 1 (6x). In 1961, the selected elites were crossed with Triticale No. 30. In 1965, (BC^2F_4) strains were developed from the F_7 generation. The most fertile ones were presented for strain propagation and national trials. The segregating fertile triticales suitable for propagation have always been hexaploids. Two varieties (Triticale No. 57 and No. 64) were released in 1968, both of which are tall and capable of yielding 30–40 q/ha in large-scale growing in good, brown, sandy soil. Under such conditions they are competitive with rye. As triticale has better digestive value than rye it has been accepted for fodder (good results in seed mixtures of 20–30% with poultry and pigs). The raw protein content of hexaploid triticales exceeds that of the wheat Bezostaya 1.

The lysine content of Triticale No. 64 is 0.50%. In pig-feeding trials the digestible raw protein content is higher than in other cereals. Protein efficiency coefficient is similarly 5–10% higher. The adaptability of both varieties is, however, poor. Under favourable conditions they can give record yields; in severe winters, they are, however, more sensitive to frost than rye. On poor, barren, sandy soil rye is more reliable. The highest yield was attained in Czechoslovakia. On large plots treated with CCC the maximum was 70–72 q/ha; in small plots the maximum was 78–81 q/ha. According to my knowledge they were successfully grown in some parts of California, too.

In Hungary, because triticale is chiefly grown on soil normally planted in rye, record yields are not to be expected in common growing. According to data of the Central Statistical Office triticale acreage and yield (q/ha) are as follow:

	1969	1970	1971	1972	1973
Wheat	27.1	28.0	30.7	31.0	34.0
Rye	12.8	10.4	14.2	14.2	15.0
Triticale	15.3	13.5	18.6	17.2	18.0

After its initial rapid advance (new plants and great interest) triticale is now rather slow in gaining further attention. One of the reasons has been dealt with earlier. Another reason is that farmers do not use it in fodder mixtures to the extent they should, despite good experience in feeding trials. In certain years triticale is heavily infected by ergot, which of course, causes feeding problems.

Despite the fact that laboratory and bakery tests gave good results in 1972, no bread standard for triticale was accepted. As long as no standard is available bread can only be baked in experimental bakeries. For this reason, triticale is treated as rye by farmers and included with data on rye in official statistics.

The half-brown and rye-type bread has a favourable shape, volume, and crumb properties. Products with better shape, bigger volume, and looser structure were obtained in loaves of 1–2 kg. The crumb is denser with thicker pore-walls than in wheat bread, but is looser, dry to the touch, and the crust is ruddier than in rye bread. The taste is quite different, being slightly sweet.

In wheat bread and confectionery, a maximum of 30% triticale flour can be used; in bread of rye type it can fully replace rye flour. Triticale flour increases the nutritional value of the product. The increased fermentation and amylase enzyme activity during breadmaking slow down the decomposition of tryptophan and lysine as well as that of vitamin B_1, which is susceptible to heat.

In quality, bread made with triticale stands between wheat and rye bread. In wheat-type bread and other bakery products, no more than 30% triticale flour can be mixed with wheat flour. In rye-type bread it can fully replace rye flour (Kada et al. 1971*a*, *b*).

Improvement of Adaptability

Triticale was developed in our time, and thus its adaptability is the poorest among cereals. It is especially susceptible to extremes of temperature, humidity, and day-length. Improvements can be achieved by developing variable primary and secondary hybrids as well as by producing new types from crosses between types favouring long daylight and those indifferent to length of daylight. Hybrids grown in different locations will be selected at Kecskemét (Kiss 1972).

Good cooperative relations have been established with several European, Asian and American breeders. We are sure that considerable good results will develop in the near future. Most of our triticales are resistant to powdery mildew, leaf rust, stem rust, and smuts (loose smut, covered smut). Under our conditions, *Fusarium* and *Claviceps* infestations cause problems. We have begun breeding for resistance to ergot. *Fusarium* is still a problem, as both wheat and rye are very susceptible to it. Several *Fusarium* species produce toxins in cereal kernels, thus preventing their use for fodder.

In the new dwarf and semi-dwarf late types, *Septoria, Helminthosporium*, and *Cladosporium* infection is important. Rye is especially susceptible but generally escapes infection due to its early maturing and tall culm. Crosses were started in 1971 to develop resistant types.

Triticale Seed Propagation

In the course of propagation, elite seed was grown on 30 ha, first-class seed on 150 ha, and second-class seed on 40 ha in 1972. Deterioration of seed was observed even within a farm. Mean grain yield of the elite was 39.8 q/ha, first-class seed 38.4 q/ha, and second-class seed 32.7 q/ha. In 1973, from nearly similar fields, the following yields were obtained: elite 42.5 q/ha, first-class seed 39.2 q/ha, and second-class seed 35.0 q/ha. Restocking of seed is therefore recommended every 3 years.

We hope that short and semi-dwarf triticales will contribute to increased yield. The test weight is still to be improved as well as a stable hexaploid level. In addition, optimal agrotechnical methods are still to be developed. We have still very much to do but we think that triticale breeders have already turned the corner. This symposium is a step forward to expand international cooperation and propagate results.

Agricultural University, Debrecen

Dr S. Erdö (1968) achieved positive results in daily gain of weight and productive efficiency of starch and protein in feeding and utilization trials with pigs. The ham weight of pigs fed with triticale was higher and the percent of liveweight of lard lower than in pigs fed barley and maize.

National Agricultural Variety Testing Institute, Budapest

Dr M. Szabó has been engaged in wheat and rye trials, and, since 1966, triticale trials (1969). In 10–12 special locations of the country the variety performance is observed. The yield capacity of triticale varies according to years. Sometimes rye yields 10–15% more (1968, 1969, 1972), other times triticale yields are higher (1967, 1970, 1971, 1973). According to statistics, triticale has given 3–4 q/ha more than rye on the national level since 1968. The present tall triticales cannot compete with wheat.

New Problems

Tall triticales are inferior to intensive wheats on good soil, because they are apt to lodge. Their dwarfing has become important. Our endeavours have met success. A_3 types (41–60 cm tall) and A_2 types (61–80 cm tall) were developed. In propagation, however, the too short straw causes difficulties. Due to their late ripening (5–6 days later than Bezostaya 1 wheat and 7–10 days later than rye) *Septoria*, *Cladosporium*, and *Helminthosporium* infections are more severe than in tall triticales. Dwarf and semi-dwarf strains have 30–36 g thousand grain weight instead of 40–50 g, which alone explains a yield loss of 25–40%. Further loss is caused by the low test weight (Triticale No. 64 70–72 kg, Bókoló and Tömzsi 60–65 kg) (Fig. 1–4).

Despite the defect mentioned above, our Bókoló propagation gave 52 q/ha on a 1-ha field in 1972 and 44 q/ha on a 15-ha field in 1973. Its raw protein content was 16–17%, lysine content 0.52–0.55%. It is hoped that after eliminating their defects the new strains can successfully cope with intensive wheats.

FIG. 1. Comparison trials of semi-dwarf secondary hexaploid triticale strains at Kecskemét, Hungary, 1973.

FIG. 2. Propagation of semi-dwarf variety candidates (Bókoló), nursery, 1973.

FIG. 3. For sandy soils, stocks of three height levels are recommended.

At present these are the obstacles we have to overcome to produce triticales of good yield capacity. The stable hexaploid level can be attained. According to Krolov (personal communication, 1973), Tarkowski (personal communication, 1973), and our own experiences (Kiss et al. 1972) the semi-dwarf Bókoló meets these requirements too. At the same time as solving breeding problems, optimal culturing methods also need to be elaborated on.

We have still much to do but we have turned the corner. Czechoslovakian triticale

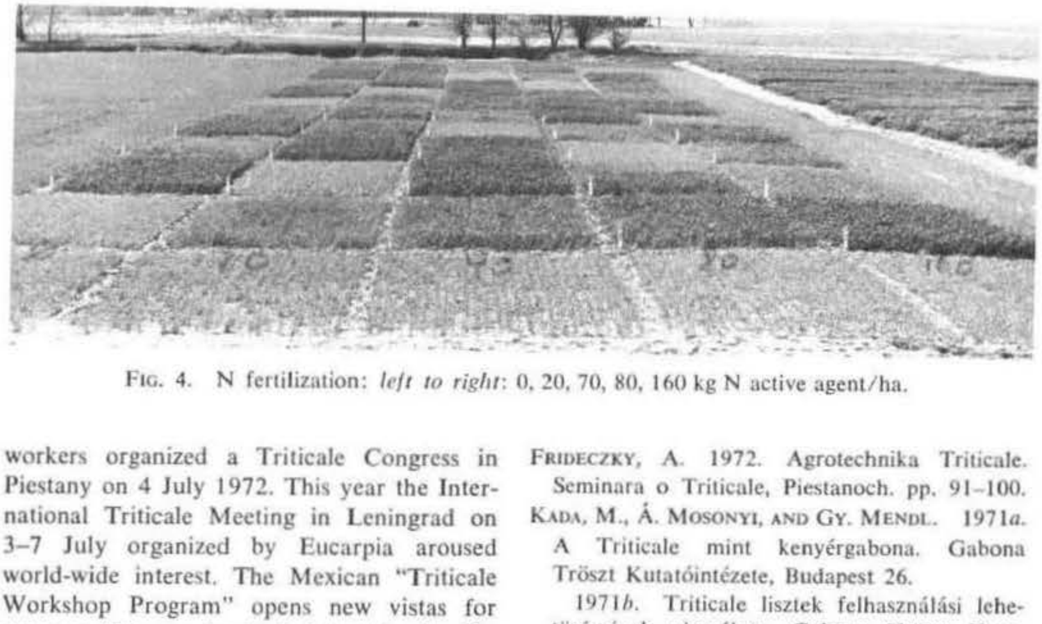

FIG. 4. N fertilization: *left to right*: 0, 20, 70, 80, 160 kg N active agent/ha.

workers organized a Triticale Congress in Piestany on 4 July 1972. This year the International Triticale Meeting in Leningrad on 3–7 July organized by Eucarpia aroused world-wide interest. The Mexican "Triticale Workshop Program" opens new vistas for progress. We are deeply indebted to the Organizing Committees for their enthusiasm. We experts, however, now have the task of attaining the aims set by the Congress as soon as possible.

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Research Work with 4x-Triticale in Germany (Berlin)

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KROLOW, K.-D. 1974. Research work with 4x-Triticale in Germany (Berlin), p. 51–60. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract This paper presents results of crosses between *Triticum monococcum* and rye, 6x-autoalloploid wheat and rye, and 6x-Triticale and rye. At the moment only the last cross has been successful. The production of 4x-Triticale with the help of this cross is described.

Crosses between 4x-Triticale and related diploid species (*T. monococcum, Aegilops speltoides, Ae. longissima, Secale cereale*) are also described. Only the cross between tetraploid triticale and diploid rye resulted in viable seeds. The possible importance of this cross is discussed.

Further results are discussed of crosses between hexaploid and tetraploid triticale to obtain secondary tetraploid triticale. In the F_2 of this cross there was strong back-regulating to the 4x level, so it was not difficult to develop such lines.

Finally, a method is described to develop 6x-Triticale with genome constitutions other than AABBRR. For instance, the cross octoploid $\times$ tetraploid triticale offers the possibility of eventually obtaining 6x-Triticale with the genome constitution AABBRR or BBDDRR. First results of this cross are presented.

Résumé Ce texte présente les résultats de croisements entre *Triticum monococcum* et seigle, blé autoploïde 6x et seigle, triticale 6x et seigle. A l'heure actuelle, seul ce dernier croisement a été couronné de succès. L'auteur décrit la production de triticale 4x grâce à ce croisement.

Il décrit également les croisements entre triticale 4x et les espèces diploïdes apparentées (*T. monococcum, Aegilops speltoides, Ae. longissima, Secale cereale*). Seul le croisement entre triticale tétraploïde et seigle diploïde a produit des semences viables. Le texte évalue l'importance possible de ce croisement.

Il traite également d'autres résultats de croisements entre triticale hexaploïde et tétraploïde, destinés à obtenir un triticale tétraploïde secondaire. La F_2 de ce croisement a été caractérisée par une tendance accentuée d'un retour au niveau 4x; il n'a donc pas été difficile de multiplier ces lignées.

L'auteur décrit enfin une méthode de création de triticales 6x ayant des combinaisons géniques autres que AABBRR. Le croisement triticale octoploïde $\times$ triticale tétraploïde offre par exemple la possibilité d'obtenir en fin de compte un triticale 6x à combinaison génique AABBRR ou BBDDRR. Le texte présente les premiers résultats de ce croisement.

REGARDING triticale breeding today, most efforts to get practical useable varieties have been made on the hexaploid and octoploid levels. Only minor attention has been paid to the tetraploid level. This is astonishing because with the aid of 4x-Triticale the genetic basis of triticale breeding can be widened on a large scale.

4x-Triticale is, for instance, not only of interest as a new triticale type with a lower ploidy level than the common triticales, but is also very useful for induction of new variability on the hexaploid level. It is perhaps possible to develop with its help new 6x-Triticale with D-genomes (AADDRR or BBDDRR). As 6x-Triticale with D-genomes may have breadmaking qualities, it should be of general interest.

Production of 4x-Triticale

There are different methods for producing 4x-Triticale. Three of them may be of practical value: (1) crosses between *T. monococcum* and rye; (2) crosses between 6x-autoalloploid wheat and rye (6x-autoalloploid wheat means amphiploids of crosses between 4x- and 2x-wheats; genome constitution: AAAABB); (3) crosses between 6x-Triticale and rye. The three crosses should result in 4x-Triticale with different cytoplasms. Cross 1 should give 4x-Triticale with 2x-wheat plasm; cross 2 should produce 4x-Triticale with 4x-wheat plasm; and cross 3 should result in 4x-Triticale with either 4x-wheat or 6x-wheat cytoplasm, depending on the primary or secondary type of the 6x-Triticale mother plants.

The crosses between *T. monococcum* and rye succeeded in our trials only when 4x-*T. monococcum* was pollinated with 2x-rye. The other cross combination: diploid × diploid and tetraploid × tetraploid produced no viable seeds. From the cross 4x-T. *mono.* × 2x-rye, two viable F_1 plants of the genome constitution AAR (3x=21) were obtained (Table 1).

The first of these two plants was back-crossed with 2x-rye to get the 4x-AARR type. It was hoped that the F_1 plant would produce unreduced gametes. This was obviously not the case and therefore no seed set was obtained.

The second F_1 plant was treated with colchicine to produce the 6x-AAAARR type and was then pollinated with 2x-rye. Also from this back-cross no seed set was obtained indicating that the colchicine treatment did not succeed in producing unreduced gametes. Nevertheless this last method may have success if more seeds are available.

The second method for producing 4x-Triticale is based on crosses between 6x-autoalloploid wheat (AAAABB) and 2x-rye, and 6x-autoalloploid wheat and 4x-rye. Both crosses resulted in viable F_1 plants. The frequency of viable seeds was considerably higher in crosses with 2x-rye (8.2%) (Table 2).

The F_1 plants from the crosses with 2x-rye (AABR) were back-crossed a second time with diploid rye to achieve, with the help of unreduced gametes, the 5x-AABRR type. These back-crosses produced only five sterile plants that had 22, 23, 23, 24, and 26 chromosomes, indicating that only reduced gametes were fertilized. To overcome this handicap, in further experiments plants should be treated with colchicine before pollination.

The other cross, between 6x-autoalloploid wheat and 4x-rye, resulted in two viable F_1 plants with 35 chromosomes (AABRR). These plants were selfed and one of them produced four offspring. Three of these had 30 chromosomes and one showed 35 chromosomes. It is expected that the three plants with 30 chromosomes will produce the wanted 4x-AARR type in the next generation.

The third method, namely the production of 4x-Triticale with the help of crosses between 6x-Triticale and 2x-rye, was the most successful one (AABBRR x RR → ABRR → AARR or BBRR or (AB) (AB) RR). This method is very simple because after crossing it is only necessary to self the 4x-ABRR F_1 plants and the further generations. Theoretically it should be possible to select out of this cross tetraploid types of the genome constitutions AARR, BBRR, and (AB) (AB)

RR (mixed genomes). It is not very difficult to cross 6x-Triticale with 2x-rye. In our trials, 6% of the pollinated flowers, on an average, produced viable seeds (Table 3). But these results are with one exception obtained from crosses between primary 6x-Triticale and 2x-rye. The cytoplasm involved is therefore that of 4x-wheat.

TABLE 1. Seed set of crosses between *T. monococcum* and *S. cereale*.

Cross	No. plants pollinated	No. ears pollinated	No. flowers pollinated	No. seeds	Freq. seeds in % of flowers	No. seeds germinated	Germinated seeds (%)	Freq. germinated seeds in % of flowers
2x-mono × 2x-rye	62	79	4634	235	5.07	–	–	–
4x-mono × 4x-rye	17	25	1412	130	9.21	–	–	–
4x-mono × 2x-rye	29	40	1960	82	4.18	2	2.44	0.10
F_1AAR × R	1	8	492	–	–	–	–	–
F_1AAR colchz. × R	1	8	484	–	–	–	–	–

TABLE 2. Seed set of crosses between 6x-autoalloploid wheat (AAAABB) and *S. cereale*.

Cross	No. plants pollinated	No. ears pollinated	No. flowers pollinated	No. seeds	Freq. seeds in % of flowers	No. seeds germinated	Germinated seeds (%)	Freq. germinated seeds in % of flowers
Turgococc. × 2x-rye	22	22	1012	93	9.19	83	89.25	8.20
Turgococc. × 4x-rye	45	51	2172	487	22.42	2	0.41	0.09
F_1AABR × RR	43	44	2816	14	0.49	5	35.71	0.18
	Chrom. no.: 22, 23, 23, 24, 26 all plants sterile							
	No unreduced gametes on the female side							
F_1AABRR selfing	1	6	370	7	1.89	4	57.14	1.08
	Chrom. no.: 35, 30, 30, 30							
	Reversion to → Chrom. no.: 28							

TABLE 3. Seed set of crosses between 6x-Triticale and 2x-rye.

Cross		No. plants pollinated	No. ears pollinated	No. flowers pollinated	No. seeds	Freq. seeds in % of flowers	No. seeds germinated	Germinated seeds (%)	Freq. germinated seeds in % of flowers
6x-(turg/cer)	× 2x-rye	35	36	2176	284	13.05	164	57.75	7.54
6x-(pxT)	× ″	21	21	1076	136	12.64	57	41.91	5.30
6x-(dicocc^6/cer)	× ″	3	3	172	10	5.81	3	30.00	1.74
6x-(turg38/cer)	× ″	1	1	56	5	8.93	3	60.00	5.36
6x-(turg40/cer)	× ″	2	2	136	12	8.82	10	83.33	7.35
6x-(turg43/cer)	× ″	2	2	84	4	4.76	2	50.00	2.38
6x-(pers/cer)	× ″	1	1	62	7	11.29	2	28.57	3.23
6x-(carth/ perenne	× ″	1	5	260	9	3.46	4	44.44	1.54
		Σ 66	70	4022	467	11.61	245	52.46	6.09

F_1ABRR → selfing → possible selection products → AARR; BBRR; (AB) (AB) RR

After five to six generations the selected 4x-lines were more or less stable. Examinations of F_5 lines (198 examined plants) revealed an aneuploid frequency of 2.5% (Table 4).

We have never found such a low frequency in progenies of our 6x- and 8x-Triticale lines. It seems, therefore, that the 4x-Triticale type is more stable than the 6x- or 8x-types.

In spite of the good cytological stability the fertility of these lines was not very high. On an average only 14 seeds per primary ear were produced in F_5 (Table 5). A high percentage of sterile plants was typical for all generations, especially for F_1 (73.2%) and F_2 (77.8%).

The yield of the F_6 lines tested on 1-m² plots was therefore very low (Table 6). Only 13.6% of the rye yield was obtained from the best line (15.4% of the 6x-Triticale yield).

Crosses Between 4x-Triticale and Other Species

To test the crossability of 4x-Triticale with related diploid species, crosses were made with *T. monococcum*, *Ae. speltoides*, and *Ae. longissima* (Table 7). None succeeded. It was therefore not possible to determine the genome constitution of the 4x-Triticale with the help of these crosses.

In contrast to this it was not difficult to cross 4x-Triticale with 2x-rye (Table 7). The F_1 plants obtained had 3x=21 chromosomes.

TABLE 4. Somatic chromosome numbers of the generations F_1 to F_5 of crosses between 6x-Triticale and 2x-rye.

Generation	No. plants examined	Chrom. no. of the plants: 26	27	28	29	30	31	32	33	34	35	36	% euploid	% aneuploids	% hypoploids	% hyperploids
F_1	66	1	4	61									92.4	7.6	7.6	–
F_2	128	4	32	42	21	11	8	4	3	1	1	1	32.8	67.2	28.1	39.1
F_3	69		10	36	17	5	1						52.2	47.8	14.5	33.3
F_4	99	1	4	77	16	1							77.8	22.2	5.0	17.2
F_5	198		1	193	3	1							97.5	2.5	0.5	2.0

TABLE 5. Sterility and fertility of the generations F_1 to F_5 of crosses between 6x-Triticale and 2x-rye.

Generation	No. plants examined	Sterile plants %	Fertile plants %	No. seeds/plant: 1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	121–130	131–140	141–150	No. seeds/plants	Germination %
F_1	97	73.2	26.8	25	1														3.4	80.2
F_2	63	77.8	22.2	10	3			1											6.7	59.6
F_3	39	30.8	69.2	17	2	4	1		1	1			1						16.7	80.3
F_4	190	16.8	83.2	58	28	18	10	9	11	4	7	6	2	2	2			1	29.1	88.4
				No. seeds/primary ear: 1–10	11–20	21–30	31–40	41–50	51–60	61–70									No. seeds/primary ear	
F_5	275	16.7	83.3	107	63	42	11	5		1									14.0	

TABLE 6. Yield of 1-m² plots of 4x-Triticale in comparison to rye, wheat, 6x-, and 8x-Triticale.

Species resp. variety	Yield (g/m^2)	% rye
4x-Triticale 2/4	85	9.6
3/2	120	13.6
5/1	95	10.7
6x-Triticale (turg/cer)	780	88.1
8x-Triticale (0)	610	68.9
6x-wheat (Carst. VIII)	880	99.4
2x-rye (petk. Sel.)	885	100.0

They may be of the genome constitution ARR, BRR, or (AB) RR. These crosses will be interesting for the development of 2x-alloplasmatic rye. It should be possible to develop rye lines with 2x-, 4x-, and 6x-wheat cytoplasm. Such alloplasmatic rye lines may be of interest for triticale breeding because these lines offer the possibility of studying the effects of different wheat cytoplasms on the rye genome. Perhaps there are influences for shortening the duration of meiosis of rye. A shortening effect would be valuable because such rye lines could show better synchronizing properties in cooperation with wheat genomes than normal rye.

Crosses Between 6x- and 4x-Triticale

To widen the genetic basis of 4x-Triticale, a second program was started involving crosses between different 6x-Triticale and 4x-Triticale. The aim of this program was to develop secondary 4x-Triticale.

These crosses caused no difficulties when the 6x-Triticales were used as mother plants. All F_1 plants had in this case 35 chromosomes. The reciprocal cross showed various chromosome numbers (34–37) and was therefore excluded from further experiments (Table 8). Also in these crosses only primary

TABLE 7. Seed set of crosses between 4x-Triticale and 2x-*T. monococcum*, 2x-*Aegilops*, and 2x-rye.

Cross	No. plants pollinated	No. ears pollinated	No. flowers pollinated	No. seeds	Freq. seeds in % of of flowers	No. seeds germinated	Germinated seeds (%)	Freq. germinated seeds in % of flowers
4x-Trc × 2x-mono	44	50	2426	–				
2x-mono × 4x-Trc	8	8	488	–				
4x-Trc × 2x-*Ae. speltoides*	13	14	622	–				
4x-Trc × 2x-*Ae. longissima*	9	9	432	–				
4x-Trc × 2x-rye	5	5	260	134	51.54	29	21.64	11.15

F_1 AAR, BRR, or (AB)RR Chrom. no. of the germinated seeds 3x = 21
ARR × RR → (A)RR → RR

TABLE 8. Seed set of crosses between 6x- and 4x-Triticale.

Cross	No. plants pollinated	No. ears pollinated	No. flowers pollinated	No. seeds	Freq. seeds in % of flowers	No. seeds germinated	Germinated seeds %	Freq. germinated seeds in % of flowers
6x-Trc × 4x-Trc	13	14	738	142	19.24	139	97.89	18.83
4x-Trc × 6x-Trc	16	16	712	104	16.69	6	5.77	0.84

F_1 (6x-Trc × 4x-Trc) Chrom. no. all plants 5x = 35
F_1 (4x-Trc × 6x-Trc) Chrom. no. 34, 35, 37

6x-Triticale was used. The newly developed secondary 4x-Triticale possessed, therefore, the cytoplasm of 4x-wheat too.

The F_1 plants showed relatively good fertility; on an average 34.5 seeds per primary ear were obtained (Table 9).

In F_2 a considerable back-regulation to the 4x level was observed. The chromosome number of the F_2 plants varied from 27 to 37, with the average number 31.09 (Table 10). The observed back-regulating tendency was very similar to the back-regulating tendency found in F_2 of crosses between 8x- and 6x-Triticale (Krolow 1969*a*, *b*). In accordance with the octoploid × hexaploid triticale cross there was no tendency of back-regulating to the parent with the higher chromosome number (Fig. 1).

Back-regulation to both levels (4x and 6x) was observed in F_2 of crosses between 6x- and 4x-wheat (Kihara 1924; Kihara and Matsumura 1940; Matsumura 1939; Grandhall 1943). The fertility of the F_2 plants was noticeably lower than the fertility of the F_1 plants (34.5). On an average only 11.8 seeds per primary ear were obtained (Table 11). The distribution of the fertility values was strikingly skewed, with the highest frequency in the category of 1–10 seeds.

In F_3 further strong back-regulating tendencies to the 4x level were obvious (Table 12). The frequency of plants with 28 chromosomes was nearly in all progenies so high that it was not difficult to select enough foundation plants for developing new secondary 4x-Triticale lines.

The cytological analysis of the cross hexaploid × tetraploid showed on the whole that for practical use it is not necessary to control the generations cytologically. In consequence of natural back regulation to the 4x level, one can expect that in F_3 and F_4 most of the plants will be secondary tetraploids. It is therefore not very difficult to widen the genetic basis of 4x-Triticale with the help of this cross.

TABLE 9. Fertility of the F_1 (6x- × 4x-Triticale).

F_1	No. plants examined	No. seeds/primary ear 0	1 10	11 20	21 30	31 40	41 50	51 60	61 70	Average no. seeds ⌀
6x-Trc × 4x-Trc										
Plants with 35 chromosomes	43		3	4	6	13	9	7	1	35.86
Plants without exact chrom. no.	7		2	2		2		1		26.14
	Σ 50		5	6	6	15	9	8	1	34.50

TABLE 10. Somatic chromosome numbers of the F_2 (6x- × 4x-Triticale).

Chrom. no. of the F_1 mother plants	No. F_2 plants examined	Chrom. no. of the F_2 plants 27	28	29	30	31	32	33	34	35	36	37	Average no. chrom. ⌀
35	182	1	8	20	39	46	33	22	10	1	1	1	31.09
	%	0.5	4.4	11.0	21.4	25.3	18.1	12.1	5.5	0.5	0.5	0.5	(diff. to chrom. no. of F_1 –3.91)
				$\underbrace{\qquad\qquad\qquad}_{87.9\%}$									

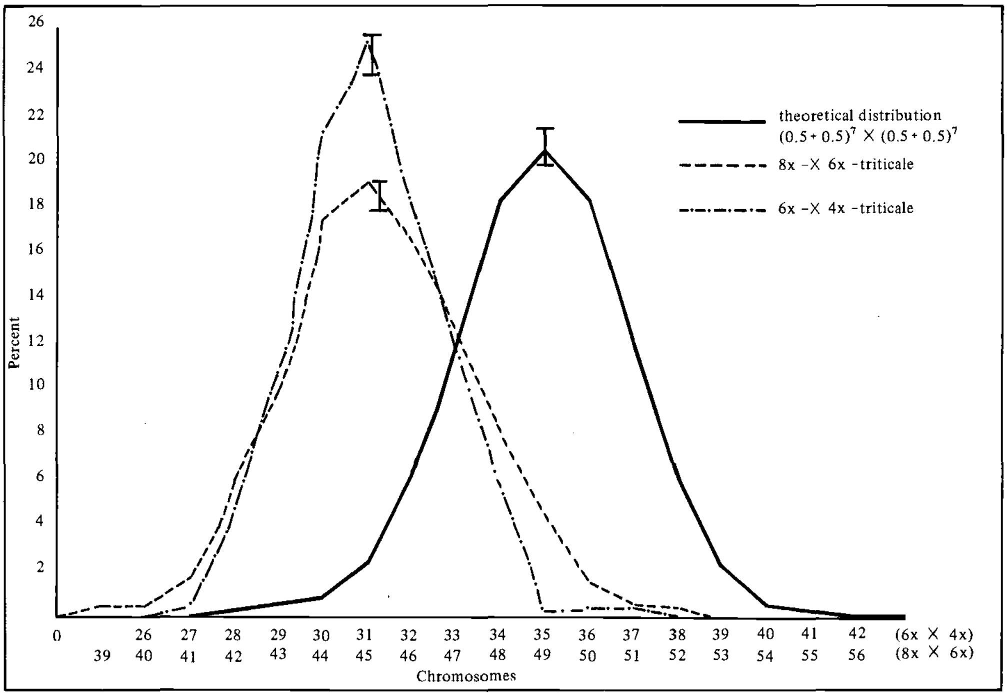

FIG. 1. Comparison between the distribution of F_2 chromosome numbers of the cross 6x- $\times$ 4x-Triticale and of the cross 8x- $\times$ 6x-Triticale.

TABLE 11. Fertility of the F_2 (6x- $\times$ 4x-Triticale).

Chrom. no. of the F_2 plants	No. F_2 plants examined	No. seeds/primary ear								Average no. seeds ϕ
		0	1 10	11 20	21 30	31 40	41 50	51 60	61 70	
27	1	1								
28	8	2	2	2	1	1				13.00
29	18	4	6	5	2	1				11.78
30	39	8	15	7	6	2	1			10.61
31	46	12	12	8	6	7	1			13.07
32	32	8	11	9	1	1	2			9.59
33	21	7	8	3	1		1		1	10.34
34	10	3	3	1	1	2				12.20
35	1		1							6.0
36	1				1					30.0
37	1		1							10.0
Plants without exact chrom. no.	52	17	12	8	5	5	2	3		13.36
F_2	Σ 230	62	71	43	24	19	7	3	1	11.83

Crosses Between 8x- and 4x-Triticale

Crosses between octoploid and tetraploid triticale may be of special interest because with their help, it is perhaps possible to obtain 6x-Triticale with genome constitutions different from the common (AABBRR) one. It should be possible to select out of these crosses 6x-Triticale with the genome constitutions AADDRR, BBDDRR, AA(BD)(BD)RR, or BB(AD) (AD)RR (Table 13). If these new types have breadmaking quality or other valuable properties, then they are very interesting for further triticale breeding.

The crosses between 8x- and 4x-Triticale succeeded in our experiments without difficulty. Seed set (22.9% of 494 florets) and viability of the seeds (92.7%) were similar to the results of the crosses between 6x- and 4x-Triticale (Table 14).

In contrast to the former cross the F_1 plants of the cross octoploid × tetraploid varied in number of chromosomes, ranging from 39 to 43, with 74.5% having 42. This variability originated from the 8x-mother plants, which, like most 8x-Triticales, were cytologically unstable (Table 15). The reciprocal cross with 4x-Triticale as mother

TABLE 12. Somatic chromosome numbers of the F_3 (6x- × 4x-Triticale).

Chrom. no. of the F_2 mother plants	No. F_3 plants examined	Chrom. no. of the F_3 plants: 26	27	28	29	30	31	32	33	34	35	36	37	38	39	Average no. chrom. ⌀	Diff. to chrom. no. of F_2 plant
28	30		1	26	3											28.07	+0.07
	%:		3.3	86.7	10.0												
29	32	1	1	8	20	2										28.66	-0.34
	%:	3.1	3.1	25.0	62.5	6.3											
30	47			19	20	7	1									28.72	-1.21
	%:			40.4	42.6	14.9	2.1										
31	45			22	16	7										28.67	-2.33
	%:			48.9	35.6	15.6											
32	40			1	10	14	9	6								30.22	-1.78
	%:			2.5	25.0	35.0	22.5	15.0									
33	40			8	13	7	7	2	2	1						29.80	-3.20
	%:			20.0	32.5	17.5	17.5	5.0	5.0	2.5							
34	40			10	17	8	2	1	2							29.32	-4.68
	%:			25.0	42.5	20.0	3.0	2.5	5.0								
37	37							11	10	5	4	1	1	3	2	33.97	-2.03
	%:							29.7	27.0	13.5	10.8	2.7	2.7	8.11	5.4		

TABLE 13. 6x-Genome combinations theoretically obtainable from crosses between 8x- and 4x-Triticale.

8x-Triticale		4x-Triticale		F_1		Possible 6x-Triticale
AABBDDRR	×	AARR	⟶	AABDRR	⟶	AABBRR AADDRR AA(BD)(BD)RR
		BBRR	⟶	BBADRR	⟶	AABBRR BBDDRR BB(AD)(AD)RR

plants resulted in seeds that were unable to germinate.

The fertility of the F_1 plants was remarkably low. On an average only 13.5 seeds per primary ear were produced. (The F_1 plants of the cross hexaploid × tetraploid produced, for instance, 34.5 seeds). As the plants with 41, 42, and 43 chromosomes were the most fertile ones, only these plants were multiplied (Table 16).

The F_2 of the plants with 41, 42, and 43 chromosomes showed a relatively wide range

TABLE 14. Seed set of crosses between 8x- and 4x-Triticale.

Cross	No. plants pollinated	No. ears pollinated	No. flowers pollinated	No. seeds	Freq. seeds in % of flowers	No. seeds germinated	Germinated seeds (%)	Freq. germinated seeds in % of flowers
8x- × 4x-Triticale	9	11	494	109	22.06 (19.24)[a]	101	92.66 (97.89)[a]	20.44 (18.83)[a]

[a]Values of the cross 6x- × 4x-Triticale.

TABLE 15. Somatic chromosome numbers of the F_1 (8x- × 4x-Triticale).

F_1	No. plants examined	Chrom. no. of the F_1 plants 39	40	41	42	43	Plants without exact chrom. no.	Average no. chrom. ϕ	% of aneuploid
8x- × 4x-Triticale	76 (47)	1	2	8	35	1	29	41.70	25.53
		%2.1	4.3	17.0	74.5	2.1			
				$\underbrace{\quad\quad}_{93.6\%}$					

TABLE 16. Fertility of the F_1 (8x- × 4x-Triticale).

Chrom. no. of F_1 plants	No. F_1 plants examined	No. seeds/primary ear 0	1–10	11–20	21–30	31–40	41–50	51–60	61–70	Average no. seeds ϕ
43	1					1				37.0
42	35	1	9	20	4	1				12.06
41	8	1	2	5						11.12
40	2	1	1							0.5
39	1		1							7.0
Plants without exact chrom. no.	29	3	7	10	5	3	1			16.10
F_1 (8x-4x)	Σ 76	6	20	35	9	5	1			13.46

TABLE 17. Somatic chromosome numbers of the F_2 (8x- × 4x-Triticale).

Chrom. no. of F_1 mother plants	No. F_2 plants examined		Chrom. no. of F_2 plants											Average no. chrom. ϕ	Diff. to chrom. no. of F_1 plant
			36	37	38	39	40	41	42	43	44	45	46		
41 (17%)	38			1	2	4	9	14	8					40.50	−0.50
		%:		2.6	5.3	10.5	23.7	36.8	21.1						
42 (75%)	36		3	1	3	6	6	7	4	4	1		1	40.28	−1.72
		%:	8.3	2.8	8.3	16.7	16.7	19.4	11.1	11.1	2.8		2.8		
43 (2%)	37			1		3	3	9	4	15	1	1		41.76	−1.24
		%:		2.7		8.1	8.1	24.3	10.8	40.5	2.7	2.7			

of chromosome numbers. In the progeny of the F_1 plant with 42 chromosomes, for instance, the number of chromosomes varied from 36 to 46, with the average number 40.28 (Table 17). This variability indicates that recombination within the haploid genomes AD or BD takes place. The frequency of plants with 42 chromosomes was in all three progenies relatively low. Only 11.1% were found in the progeny of the F_1 plant with 42 chromosomes. It is now necessary to select these plants and to prove the stabilization of their chromosome number in further generations.

If it proves possible to select 6x types with breadmaking quality and full-shaped kernels out of this cross, then triticale will become interesting not only as a fodder crop but also as a crop suitable for human nutrition. In any case the investigations show that 4x-Triticale offers the possibility to induce new variation into the present triticale material.

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Triticale Research Program in the United Kingdom

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Abstract A hexaploid triticale breeding program was initiated at Cambridge in 1970. Twenty-two primary triticales have been synthesized to try to introduce more local adaption, winter hardiness, and dwarfness into the breeding material.

Two potential problems that are associated with the widespread use of *T. aestivum* in improvement programs were investigated. Firstly, 32 hexaploid triticale lines were crossed to *T. aestivum* Chinese Spring and the meiosis of the F_1 hybrids was analyzed. In 29 of the lines, a D chromosome had been substituted for a rye chromosome. Secondly, hybrid necrosis was observed in many crosses between primary triticales and triticale selections from the CIMMYT program. Most primary triticales were thought to contain the Ne_1 gene and some triticale selections the Ne_2 gene, which had been introduced from *T. aestivum*.

In first-year trials many selections outyielded the locally adapted bread wheats. Selection for lateness in Mexico of early generation material and subsequent selection for two generations at Cambridge produced higher yielding material than could be obtained from the International Triticale Yield or Screening Nurseries.

Résumé Un programme de sélection du triticale hexaploïde a été mis en place à Cambridge en 1970. On a procédé à la synthèse de 22 triticales primaires afin de tenter d'introduire dans le matériel génétique une meilleure adaptation aux conditions locales, une plus grande résistance à l'hiver et un nanisme plus poussé.

Deux problèmes potentiels liés à l'utilisation sur une grande échelle de *T. aestivum* dans les programmes d'amélioration ont fait l'objet de recherches. On a d'abord croisé 32 lignées hexaploïdes de triticale avec du *T. aestivum* chinois de printemps et l'on a analysé la méiose des hybrides F_1. Dans 29 des lignées, un chromosome D a été substitué à un chromosome du seigle. On a procédé ensuite à des observations sur la nécrose hybridaire intervenant dans de nombreux croisements, surtout entre triticales primaires et des triticales obtenus du programme du CIMMYT. Il semble que la plupart des triticales primaires contiennent le gène Ne_1 et que quelques-unes de ces obtentions de triticale contiennent le gène Ne_2, introduit à partir de *T. aestivum*.

Au cours de la première année d'essais, de nombreuses sélections ont dépassé le rendement des blés panifiables d'adaptation locale. La sélection effectuée au Mexique sur du matériel de première génération en vue de la tardiveté et la sélection postérieure effectuée à Cambridge sur deux générations ont produit un matériel à rendement plus élevé qu'il n'aurait été possible d'en obtenir à partir des pépinières internationales de sélection ou de multiplication du triticale en fonction du rendement.

In the United Kingdom triticale breeding is restricted mainly to the Plant Breeding Institute, Cambridge, but developments are also being monitored by several private plant-breeding companies. The Cambridge program was started in 1970 after a colleague, John Bingham, had spent a working visit with CIMMYT in Mexico. Selection for late ear emergence and maturity in Mexico produced the basic material for the present breeding program in hexaploid triticales.

General Breeding Methods

Many papers have dealt with the breeding methods commonly used in hexaploid triticale improvement programs (Sanchez-Monge 1958; Pissarev 1963; Larter et al. 1968; Jenkins 1969; Larter et al. 1970; Sisodia and McGinnis 1970; Zillinsky and Borlaug 1971). Basically three types of cross are employed: (*a*) between triticale selections; (*b*) between triticale selections and *T. aestivum* or octoploid triticales; (*c*) between triticale selections and newly synthesized hexaploid triticales. Various aspects of these methods of improvement will be discussed in this paper.

Synthesizing New Hexaploid Triticales

The synthesis of new hexaploid triticales provides the easiest method of introducing variation from the parental species. At Cambridge, experience gained by the Cytogenetics department in embryo culture and colchicining techniques has been used in the synthesis of new triticales.

Crosses are usually made in the glasshouse, under artificial illumination, in the winter months. Crossing in the field is less satisfactory because fungi growing on the developing grains often contaminate the culture medium when the embryos are excised. The tetraploid wheat is used as the female parent and crossability figures of 0–93% have been obtained. Twenty-one days after pollination the embryos are removed and cultured on an Orchid agar medium containing inorganic salts and sucrose but no growth hormones. At 27–30°C, under constant illumination, the onset of root and shoot development takes from 2 wk to 6 mo but thereafter growth is usually rapid and the young plants can soon be potted into soil. About 25% of the hybrid grains produce plants.

The hybrid plants are treated with colchicine when they possess several tillers (Bell 1950). One cc of 0.3% colchicine solution is applied in a glass phial to tillers that have been cut off cleanly about 3 cm from their base. The treated tillers die but other tillers survive to produce ears that are examined for fertile sectors as indicated by dehisced anthers. Sterile ears are removed to encourage secondary tillers to develop and ears containing fertile sectors are bagged to promote grain setting. The 12% of hybrid plants successfully doubled produce from one to several hundred triticale grains each.

The removal of the embryos before the grains reach maturity is the only modification to the original method that has been successfully used to produce a wide range of amphiploids. Further changes might, however, be desirable for the large scale synthesis of triticales. No experimental evidence is available but the culture medium and colchicining technique could perhaps be improved. In particular, many small embryos that would probably not survive to maturity are obtained. Kaltsikes (personal communication) has suggested a medium that is used at Winnipeg and contains growth-promoting hormones as being more suitable for these smaller embryos. Additionally, many of the hybrid plants appear relatively unaffected by the present colchicine treatment. The application of a higher concentration or volume of colchicine solution to each plant might increase the proportion of hybrids that are successfully doubled.

Twenty-two triticales have so far been synthesized. Initially *T. durum* selections from other countries and European ryes were used as parents. Selections from the tetraploid wheat breeding program at the Institute are now being increasingly used in the synthesis of new triticales.

The program has shown that both parents must be winter types to produce a winter triticale. Several winter–spring combinations have also been made and these may prove to be sufficiently hardy for U.K. conditions. Winter tetraploid wheat selections from *T. durum* × *T. turgidum* crosses will provide more scope for the synthesis of winter triticales. Seven triticales have been made from Snoopy dwarf rye and semi-dwarf, Norin 10-derived *T. durum* selections. None of these triticales appears to be noticeably shorter than those in which a tall rye was used as the parent. This has still to be confirmed by growing the new triticales in the same environmental conditions.

D Chromosomes in Hexaploid Triticale

So far triticale × *T. aestivum* crosses have formed only a minor part of the Institute breeding program. However, two potential breeding problems associated with the use of *T. aestivum*, the introduction of D chromosomes into hexaploid triticales and hybrid necrosis, have been studied.

Recently doubt has been expressed about the genomic constitution of some triticales. Gustafson and Zillinsky (1973) have found a single Armadillo line to possess at least one D chromosome (2D) and possibly a second (5D) substituted for rye chromosomes. The possibility that D genome chromosomes have been substituted for rye chromosomes raises several basic questions for the triticale breeder:

(a) how many triticale lines have D genome chromosomes substituted for rye chromosomes and how many substitutions do they possess?

(b) which chromosomes are involved?

(c) how much of the improvement in triticales can be attributed to these substitutions?

(d) should we abandon work on triticales and concentrate on a synthetic species with a mixed third genome, and, if so, what breeding methods would we use?

To obtain answers to at least some of these questions, a cytological study was carried out, using some of the best triticale lines from the Cambridge breeding program and some lines from the CIMMYT program. Information about the lines is given in Table 1.

Single plants of these lines were crossed with *T. aestivum* Chinese Spring and the meiosis of the F_1 hybrids was analyzed. A summary of the results is given in Table 2.

The only lines that were found to be true triticales, i.e., to possess the complete rye genome, were TG4 and B5. B5 was, however, homozygous for a translocation involving a D chromosome and the A or B genome. Most of the triticale lines contained a pair of D chromosomes substituted for a pair of rye

TABLE 1. Triticale lines analyzed for D Chromosomes.

7	Armadillo lines that were selected in Mexico for late ear emergence and maturity and have subsequently been twice selected at Cambridge (A1–A7)
13	Beaver lines selected in the same way (B1–B13)
3	Beaver lines from the 2nd ITSN, once selected at Cambridge (ITSN 47, 48, 53)
8	Lines received directly from F. J. Zillinsky
	M1 Selection from octaploid triticale bulk No. 91
	M2 Koala (Sonora 64-P4160 × *T. polonicum* Mika/Sonora 64) (Rye Merced – Ghiza × Carleton)
	M3 Maya II × Armadillo 'S' × 1517 (Inia × Guarda)^2
	M4 Hexaploid selection from an octaploid bulk outcross
	M5 Hexaploid selection from an octaploid bulk outcross
	M6 Selection from F_4 bulk octaploid × hexaploid
	M7 Camel ×–1648–2N–1M–0Y
	M8 Selection from F_6 triticale bulk
1	Newly synthesized triticale that had been maintained by bagging TG4 (Crane 'S' × F_3 Tunisia–D–63–13–b) × Rye Lovaszpatonai

TABLE 2. Genomic constitution of triticale lines.

Constitution	No. lines	Line designation
No D pairs, 7 rye pairs	1	TG4
No D pairs, 7 rye pairs, and 1 D translocated into A or B genome	1	B5
1 D pair, 6 rye pairs	26	A1, A2, A3, A4, A5, A6, A7 B1, B2, B3, B4, B6, B9, B10, B11, B12, B13 ITSN 47, 48, 53 M1, M2, M3, M4, M6, M8
1 D pair, 6 rye pairs, and 1 D translocated into A or B genome	3	B7, B8 M7
2 D pairs, 5 rye pairs	1	M5

chromosomes, but only one line had two pairs substituted. Three other lines, however, possessed a pair of substituted D chromosomes and a translocation involving another D chromosome. All of the selections analyzed from the two breeding programs, therefore, contained some D chromosomal material from *T. aestivum*. This study did not, however, determine which D chromosomes were present and which rye chromosomes absent from the various lines. At the moment, therefore, it is only speculation to suggest that a particular pair of D chromosomes is advantageous or a pair of rye chromosomes disadvantageous in hexaploid triticales.

A triticale × *T. aestivum* hybrid should form 14 bivalents and 14 univalents at first metaphase of meiosis. When a "triticale" with a D chromosome disomically substituted for a pair of rye chromosomes is used, the pairing increases to 15 bivalents and 12 univalents or the equivalent, e.g., 13 bivalents, 1 quadrivalent, and 12 univalents. However, as many hybrids could make quadrivalents, failure to do so in some cells, by forming a trivalent and univalent or four univalents, led to a reduction in the number of chromosomes paired. This would tend to be further reduced by differences between the A and B genomes of the triticales and the *T. aestivum* parent, Chinese Spring.

Table 3 shows the level of pairing actually observed for hybrids between Chinese Spring

TABLE 3. Mean pairing of various triticale × Chinese Spring hybrids (2 plants of each hybrid and 20 cells/plant).

Triticale type	Max pairing configuration	% of cells with max pairing configuration	Mean no. bivalents	Mean no. trivalents	Mean no. quadrivalents
No. D pairs (TG4)	14 bivalents	35	13.25	0	0
No. D pairs + 1 D translocated (B5)	13 bivalents 1 trivalent	25	11.50	0.65	0.38
1 D pair	15 bivalents				
Highest pairing (B3)		75	14.75	0	0.025
Lowest pairing (A2)		25	12.80	0.20	0.55
1 D pair + 1 D translocated	14 bivalents 1 trivalent				
Highest pairing (B8)		55	13.80	0.75	0
Lowest pairing (M7)[a]		0	12.65	0.25	0.45
2 D pairs (M5)	16 bivalents	32	15.04	0.04	0

[a]Plants of this hybrid formed 15 bivalents in 15% of the cells and a trivalent, in addition to any quadrivalents formed, in 12.5% of the cells scored. The maximum possible pairing configuration was, however, not observed.

and triticale lines from the different classes that had been recognized.

The level of substitution involved is unlikely to affect seriously the breeding methods currently employed. However, it will probably be necessary to grow larger F_2 populations to obtain fertile segregants. When making crosses, the number of florets pollinated will have to be further increased to allow for the reduced crossability of the parents and the lower fertility of the F_1 hybrids.

Hybrid Necrosis

Another problem that is associated with the use of *T. aestivum* or octoploid triticales in hexaploid triticale breeding programs is hybrid necrosis. This physiological disorder results when two complementary genes, Ne_1 and Ne_2, are incorporated into a single genotype. The effect on the plants depends upon the strength of the alleles that are present in the parents (Hermsen 1963*a*), the most severe combinations resulting in the early death of the F_1 hybrids. The genes and alleles that are present in varieties of *T. aestivum* have been well documented by Hermsen (1963*a*, *b*) and Zeven (1966, 1968, 1969, 1971) but relatively little is known about the distribution of the genes in tetraploid wheats. Hybrid necrosis has also been a problem in *T. durum* × *T. aestivum* crosses in the tetraploid wheat breeding program at Cambridge. A survey of 20 *T. durum* selections from the CIMMYT program involving lines from many parts of the world indicated that all possessed the Ne_1^s allele.

This allele is probably, therefore, carried by many of the newly synthesized triticales. Hybrid necrosis is likely to occur if these are hybridized with triticale selections derived from crosses involving Ne_2 carrying *T. aestivum* varieties. At Cambridge hybrid necrosis has been observed in F_1's between new triticales and the lines from Mexico that were used in the D chromosome study (Table 1). Out of 86 crosses, 16 produced no F_2 grain because the hybrid necrosis was lethal. A further 14 produced reduced amounts because either the allelic combination diminished the vigour of the hybrids, or the triticale selections were heterogeneous or heterozygous for the Ne_2 gene.

Yield Results

At Cambridge, triticales have shown little resistance to lodging and have produced grain samples of poor appearance due to the shrivelled grain, pre-harvest germination, and contamination by ergot (*Claviceps purpurea*). Although these problems have been recognized, selection for yield components has so far been considered more important in the breeding program.

The first triticale yield trials were grown at Cambridge in 1973. As all the triticales were of Mexican origin and the growing conditions at Cambridge are very different from those in Mexico, particularly in daylength, temperature, and rainfall distribution, it is interesting to compare the results of the CIMMYT yield nurseries with the International Spring Wheat Yield Nursery (ISWYN), the International Durum Yield Nursery (IDYN), and the International Triticale Yield Nursery (ITYN) (Table 4). The controls in the trials were N.W. European, spring varieties of *T. aestivum*.

The bread wheats appear to be the best adapted and the durum wheats the least adapted to U.K. conditions. This ranking probably also applies to general adaptability since none of the varieties tested were selected in environments similar to those of Cambridge. Triticales may, in general, show wider adaptability than was indicated because all of the entries in the trial were selected in Mexico, whereas the other yield trials contained varieties from many different countries. The exceptionally low yields in the IDYN reflect the susceptibility of most of the entries to the very severe attacks of mildew (*Erysiphe graminis*) and *Septoria* that developed. No mildew was seen in the ITYN, but low to moderate infections of *Septoria* were observed. This is the most important leaf pathogen of hexaploid triticales at Cambridge.

Lines from the 2nd and 3rd International Triticale Screening Nurseries (ITSN) and from

TABLE 4. CIMMYT International Yield Nursery results (yields expressed as percentage of *T. aestivum* Maris Dove).

Trial	Best yielding selection		Best yielding N. W. European *T. aestivum* control		No. selections tested	No. countries	No. selections outyielding Maris Dove	No. selections outyielding best control
9th ISWYN	Soltane	(120%)	Maris Bulter	(116%)	49	17	21	2
4th IDYN	Hercules	(74%)	Maris Dove	(100%)[a]	23	9	0	0
4th ITYN	Maya II–Arm 'S'	(105%)	Sirius	(120%)	21	1	1	0

[a]The higher yielding *T. aestivum* controls were not included in this trial.

TABLE 5. Triticale yield results (yields expressed as percentage of *T. aestivum* Maris Dove).

	No. generations of selection at Cambridge	Best yielding selection	Best yielding N.W. European *T. aestivum* control	No. selections tested	No. selections outyielding Maris Dove	No. selections outyielding best control
4th ITYN	0	Maya II–Arm 'S' (105%)	Sirius (120%)	21	1	0
2nd and 3rd ITSN selections	1	Beaver 'S' (121%)	Kolibri (121%)	32	15	0
Late selections in Mexico						
(*a*) Armadillo lines	2	A35, A91 (129%)	Maris Halberd (119%)	96	72	9
(*b*) Beaver lines	2	B7 (135%)	Maris Butler (121%)	48	35	7

the material selected for lateness in Mexico by Bingham were also grown in yield trials, the results of which are summarized in Table 5.

The highest yielding lines came from the late-maturing Mexican material, which had been twice selected at Cambridge for fertility, ear size, and tiller production. The ITSN's and the ITYN in particular do not appear to contain the type of material that is best adapted to U.K. conditions. At Cambridge, early generation Mexican material is therefore essential for the selection of well-adapted lines. The yields of the Institute selections are encouraging, not only for the triticale breeding program at Cambridge, but also for those in other countries, because they indicate that Mexican material possesses sufficient variability for selection to be effective in widely differing environments.

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Progress in the Development of Triticale in Canada

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Larter, E. N. 1974. Progress in the development of triticale in Canada, p. 69–74. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The problems and objectives of the triticale research program at the University of Manitoba, Winnipeg, Canada, are outlined for the 20 years that it has been underway. Yields of the developing hexaploid ($2n = 6x = 42$) spring-type triticales have steadily increased over the years. This past season the mean yield of all advanced lines was 105% of the bread wheat variety Manitou and the commercial triticale variety Rosner. The highest yielding lines exceeded these varieties by as much as 30%; however, further testing is necessary to establish their yielding stability over a wider area.

The nutritional composition of triticales is satisfactory based on small- and large-animal feeding trials. With emphasis on improvement of kernel type, protein content has declined from the levels reported early in the program; however, the average percent protein of today's triticale is approximately 2 units above the standard bread wheat varieties (i.e. approximately 15% protein on a 14% moisture basis and a 5.7 conversion factor). Lysine content in present triticales remains 1.5–2.0% higher than in wheat.

Although there are areas throughout the world in which triticale would be suited for agricultural production today, there is still the need to increase its adaptability. The continual synthesis of new amphiploids and the intercrossing of these existing hexaploid and octoploid types is rapidly broadening the genetic base of triticale, thus making it more competitive as a crop species.

Résumé Les objectifs et les problèmes du programme de recherche entrepris depuis 20 ans à l'Université du Manitoba à Winnipeg, Canada, sont ici soulignés. Les rendements des triticales de printemps hexaploïdes ($2n = 6x = 42$) en cours de sélection se sont accrus régulièrement au cours des années. Lors de la campagne dernière, la moyenne du rendement de l'ensemble des variétés avancées s'est établie à 105% de celui du blé de panification Manitou et de la variété commerciale de triticale Rosner. Les lignées dont le rendement a été le plus important les dépassaient de 30%; il est cependant nécessaire de poursuivre les essais afin d'assurer la stabilité du rendement de ces lignées sur une aire plus étendue.

Selon les essais d'alimentation effectués sur petits et gros animaux, la composition du triticale est satisfaisante sur le plan nutritif. L'amélioration poussée du type du grain s'est traduite par une diminution de la teneur en protéine par rapport aux chiffres précédemment indiqués au cours du programme; la teneur moyenne en protéine des triticales d'aujourd'hui reste cependant supérieure d'environ deux unités à celle des variétés de blé normales de blé panifiable (c.-à-d. 15% environ de protéine avec une humidité de 14% et un facteur conversion de 5.7). Dans les triticales actuels, la teneur en lysine reste supérieure de 1.5 à 2% à celle du blé.

Il existe à travers le monde des régions où le triticale conviendrait actuellement à la production agricole, mais il est nécessaire d'accroître encore ses facultés d'adaptation. La synthèse permanente de nouveaux amphiploïdes et leur croisement avec les hexaploïdes et octoploïdes existants élargit rapidement l'assise génétique des triticales, faisant de ces derniers une espèce cultivée de plus en plus intéressante.

1974 will mark the 20th anniversary of a full-time triticale breeding program at the University of Manitoba. Through a private endowment to the University by the Bronfman Family Foundation, a Research Chair in Agronomy was established within our Plant Science Department in 1954. This established the working nucleus for the triticale breeding and research program as it exists today. Furthermore, it was the direct result of this sponsorship that "sparked" additional much-needed support from both public and private sources. The year 1971 proved to be a milestone in the development of triticale, because it was that year that the Canadian International Development Agency (CIDA) elected to provide substantial financial support, as administered by the International Development Research Centre, Ottawa (IDRC), for the development of triticale as a human food in developing countries of the world. As part of an overall international program, it was natural that our activities would become closely integrated with those of CIMMYT's in Mexico. Moreover, with our program located at a University, we have the opportunity to conduct "basic" studies on specific problems with which the plant breeder is confronted. From the beginning, therefore, our program has been interdisciplinary in nature, involving in addition to plant breeding per se the disciplines of plant cytogenetics, as well as studies on the nutrition, biochemistry, and utilization of the grain.

The main emphasis in the improvement of triticale at the U of M has been directed toward developing a hexaploid (6x) form ($2n = 42$). We have, of course, utilized octoploid (8x) types, but more in the role of parental material for crosses with 6x types. Earlier observations by European workers showed that hexaploid plant types recovered from 8x × 6x crosses are superior in certain agronomic characteristics to hexaploids derived directly from tetraploid wheat–rye crosses. These differences they attribute to the effect of cytoplasm (Kiss 1966; Pissarev 1966).

A recent study made in this department (Hsam 1973; Larter and Hsam 1973) has confirmed these earlier observations by means of control comparisons between progenies from reciprocal 8x × 6x crosses. Each reciprocal pair was known to be genetically identical and differing only in its source of cytoplasm. An 8x × 6x cross contributes the cytoplasm of hexaploid wheat by way of the octoploid triticale, whereas the reciprocal cross (6x × 8x) contributes cytoplasm from tetraploid wheat. Beneficial characteristics contributed by the octoploid parents include: (*a*) a more meiotically stable progeny (fewer univalents); (*b*) improved fertility; (*c*) a more plump kernel; (*d*) a lower amylase activity (a higher amylase activity being closely associated with poor seed development); and (*e*) a higher lysine content.

As an explanation for these obvious desirable contributions of hexaploid wheat cytoplasm to triticale development, it is necessary to reflect momentarily on the evolution of the species *Triticum aestivum* (common wheat). Today the majority of wheat workers agree that the cytoplasm of our common wheats was contributed by some tetraploid species. Through the tens of thousands of years of evolutionary change during the development of the hexaploid form, tetraploid wheat cytoplasm became modified to function harmoniously with a hexaploid (ABD) nucleus. Therefore when we synthesize triticale using hexaploid cytoplasm, we are using a cytoplasm already modified to coexist with a foreign genome (the D genome). Therefore, when associated with yet another foreign genome, the R genome, hexaploid wheat cytoplasm would be more adjusted than the relatively unmodified cytoplasm from tetraploid wheat.

Since we are concentrating on the development of hexaploid triticale, one might ask why are we not concentrating on the development of an 8x triticale, which obviously would already carry the hexaploid cytoplasm component. The early triticale breeders, of course, did use these forms extensively. It was natural that these forms would have to be developed from wheat–rye crosses using the early strains or varieties of common wheat that were basically "land" varieties with a narrow genetic base and with limited adaptability. It would not be too surprising that these early 8x triticales were rather disappointing in their performance at that time. It was largely on the basis of the results of these workers that we and others have since looked to the hexaploid triticale as being more promising. The results today attest to the fact that this decision was a correct one.

Notwithstanding this, I wish to emphasize the need for renewed effort in the development of octoploid triticales. We have recently seen a revolution in the varietal picture of our hexaploid common wheats, i.e. the so-called Mexican semi-dwarfs. These have a much wider genetic base than any wheats heretofore and possess a greatly extended adaptability. Our own experience has shown that certain combinations of these wheats with rye combined extremely well in the synthesis of octoploid triticales with high fertility. The exploitation of these octoploids certainly requires our further attention.

As well, we are devoting our attention exclusively to the development of a spring triticale. Experience during the early stages of the program clearly indicated that with possible exceptions of a few foreign introductions (principally from Russia), there was insufficient winter hardiness in the triticale to enable it to survive under our conditions in western Canada. For example, triticales synthesized from our most winter-hardy rye varieties and with our hardiest winter wheats, tend to resemble the less resistant wheat parent in their degree of hardiness. Nevertheless, we are utilizing winter types in crosses with our spring triticale in an attempt to transfer and exploit some of the agronomic characteristics known to exist in the former.

In Canada one variety of triticale (Rosner) was released for production in 1970 (Larter et al. 1970). At present there are approximately 1000 acres of Rosner in production, much of which is under contract with distilleries. As there is at present no grading system established to handle triticale, it cannot be sold through normal seed grain channels. However, it is officially recommended as a grain for local feeding of livestock and some farmers are using it in mixtures with other grains.

On the basis of analytical determinations, triticale grown under our conditions has generally exhibited an increased lysine content relative to wheat and a protein level 1–2 units higher than our bread wheats (Table 1).

TABLE 1. Summary of performance of advanced lines of triticales in 1973 tests.

Yield test no.	No. entries	No. entries better than			Best triticale as a % of		
		Rosner	70HN458	Glenlea	Rosner	70HN458	Glenlea
308	58	43	–	0	139	–	81
309	58	18	–	0	129	–	90
310	37	32	29	3	142	141	109
311	27	16	12	0	136	124	88
312	47	28	5	2	159	131	118
Total	227	137	46	5			
%		60	20	2			

In one sense it has been rather disturbing to review the long-term trends in protein levels in our triticale and to find that there has occurred over the years a gradual decline of nitrogen level. On the positive side, I feel that it is only natural to expect some fall-off of protein level as we improve kernel plumpness (i.e. by increasing the amount of endosperm tissue relative to pericarp, or bran) through intensive selection. At the same time, we as plant breeders will have to be constantly on the lookout for those combinations that will result in a minimal reduction of protein percentage in relation to the increased plumpness of kernel.

Small-animal (rats and mice) feeding trials in our laboratory show that the growth response of these animals fed pure triticale is consistently higher than the same animals fed wheat. Test diets prepared from the grain of seven different crop species showed that only soybean meal resulted in gains greater than those obtained from triticale diets. Moreover, in a study just completed, we have shown that a chemical compound known as resorcinol, usually found in considerable quantities in rye grain and considered toxic to animals feeding on this grain, is not harmful when fed to mice in quantities 10 times the normal levels. Although reports have been contradictory, it is felt that where we can rule out ergot as a possible source of contamination of grain rations, the nutritional value of triticale, particularly when fed to poultry and hogs, exceeds that of wheat and is equal, if not superior, to barley.

There are three areas in our triticale breeding program that are receiving major attention: (1) escalation of yields; (2) improvement of kernel type; and (3) incorporation of genetic resistance to ergot (*Claviceps purpurea*).

To provide a base figure for yields, Rosner under trial plot conditions equals the yields of our current bread wheat varieties (long-term average of 1.5 tons/ha). However, Rosner grown under the solid-seeding conditions of commercial field production invariably yields higher than when grown in small plot tests. We cannot explain the reason for this differential reaction, nor do we know if it is a condition general to a wide spectrum of triticales or peculiar only to Rosner. We are confident that we have lines now undergoing preliminary testing that will out-yield Rosner (Table 2; Fig.1). This material is the product of multi-parent crosses utilizing the relatively high tillering Rosner type from our own program and the highly fertile Armadillos from CIMMYT. In addition, we are introducing genes for increased spike length into our material and at the same time maintaining selection pressure for high fertility. On the basis of this type of evaluation, over 640 crosses were made between triticales this season, and from last year's crossing program, approximately 365 F_1 populations were visually examined and selected.

Kernel shrivelling has been characteristic of triticale since the very beginning. Through the added support by the Canadian Inter-

TABLE 2. Mean percent protein and lysine of advanced lines of triticale compared to wheat, 1972.

	Protein (*14% moisture, 5.7 C.F.*)	Lysine (*g/100 g protein*)
Mean	13.3	3.55
	(11.0–15.8)	(2.73–4.56)
Neepawa	14.4	2.90
Glenlea	13.2	2.81
Rosner	12.6	3.37

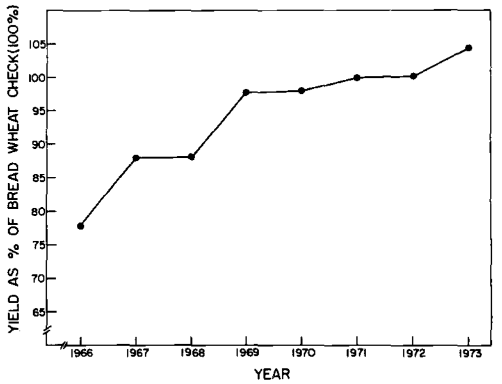

FIG. 1. Annual mean yields of advanced lines of triticale, 1966–73.

national Development Agency (CIDA), we are now able to obtain some basic knowledge of the underlying causes of this abnormality. Some studies conducted by Hill et al. (1973) have shown that abnormally high levels of the enzyme amylase are associated with a precocious breakdown of starch kernels in the endosperm, thus inducing kernel shrivelling. Furthermore, Darvey (1973) is attempting to associate specific chromosomes of rye with seed shrivelling and concludes that there are at least three that he has identified as having major effects, viz. chromosomes 4/7R, 5R, and 6R.

It is this type of information that when assembled will permit a more scientific attack on the problem. In the meantime, a plant breeder can select for plump kernels and attempt to eventually move the mean of the population toward the upper limits. In our program we are using a mechanical selection method (a gravity table) to "screen" relatively large bulk quantities of segregating populations. As this is only the second cycle of such selection, it is too early to measure our success. Meanwhile, through a series of visual selections, we have isolated several lines of a cross between a newly synthesized amphiploid and rye in which the 1000 kernel weight averages over 51 g compared with Rosner with a kernel weight of approximately 43 g per 1000 kernels. Full-scale evaluation of these lines is planned for next season.

The ergot problem, although not a universal one, can pose a serious bottleneck to a triticale program. However, progress is being made: the highly fertile Armadillo strains and their derivatives show a very marked reduction in ergot infection, presumably the result of their almost complete fertility. In other words, as we improve fertility of triticale there will be relatively fewer sterile florets vulnerable to infection by the ergot organism.

The ideal solution to this problem is the incorporation of genetic resistance to the organism. But because ergot does not cause devastating losses at any one time, nor is it an annual threat, practically no work has been done on resistance to this disease. However, our senior plant pathologist, Dr C. C. Bernier, devised techniques to screen for resistance among wheats and more recently among rye varieties. He has now isolated resistance among a number of wheats including mainly monococcums and tetraploids, but also a few hexaploids of the spelta type (personal communication). He has more recently found strains of rye varying in their degree of susceptibility. Numerous wheat–rye crosses have been made using the resistant wheat as parents and over 1200 embryos have been cultured; the F_1 hybrids are now being doubled in the greenhouse. How these genetic systems for resistance will operate in a triticale background remains to be determined.

In conclusion, compared with wheat the period of time (in the evolutionary sense) that triticale has been under more or less intensive study is an infinitesimally short one. However, in this brief period it has risen from its very early status as a crop grown for the sake of curiosity or for pure research reasons, to one of considerable promise. Our work along with others has shown it to be nutritionally superior to wheat as an animal feed, and it is also growing in importance as forage. Moreover, the progress that has been made by the Food and Fibre Research and Development, Inc., Texas, marks a very important step forward in the development of triticale as a human food. It is in this area that much more "utilization research" could be expended.

Triticale workers have every justification to feel proud of the progress that has been made with this species in the brief span of time devoted to it. There is, of course, much work still to be done. However, with the enthusiasm that we see growing year by year, I am convinced that triticale will in the near future take its place alongside the already long-established cereal crops in world agriculture.

Acknowledgments

The author expresses his gratitude to the Bronfman Family Foundation, the Canadian International Development Agency, and the National Research Council of Canada for their generous support of the triticale program at the University of Manitoba.

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Triticale: Its Potential as a Cereal Crop in the United States of America[1]

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METZGER, R. J. 1974. Triticale: its potential as a cereal crop in the United States of America, p. 75–80. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Modern triticale varieties have been tested in the United States since 1967. With a few exceptions, the best-adapted wheat varieties have yielded more grain per acre than the best available triticale lines. This superiority was anticipated because very little effort has been devoted to the development of triticale varieties for use in the various climatic regions of the United States and particularly where the majority of the cereal grains planted are of the winter type.

Breeders have identified many characters in triticale that need improving. Among them are kernel conformation, floret fertility, tillering ability, standability, winter hardiness, disease resistance, and response to fertilizers. Triticale lines are available that are superior to present varieties in one or more of these characters; however, they are also deficient for certain of these characteristics as well. Therefore, if triticale is to be competitive with other cereal grains, plant breeders must concentrate on assembling in a variety the characters needed to ensure satisfactory production of varieties in a given locality.

Résumé Les variétés modernes de triticale font depuis 1967 l'objet d'essais aux Etats-Unis. A quelques exceptions près, les variétés de blé les mieux adaptées ont donné des rendements supérieurs à ceux des meilleures lignées de triticale disponibles. On prévoyait cette supériorité du fait des initiatives minimes qui ont été consacrées à la création de variétés de triticale utilisables dans les diverses régions climatiques des Etats-Unis, en particulier là où la majorité des céréales-grain utilisées sont du type des céréales d'automne.

Les obtenteurs ont répertorié chez les triticales un grand nombre de caractères nécessitant des améliorations, dont la conformation du grain, la fertilité des fleurs, les capacités de tallage, la densité de peuplement, la résistance au froid et aux maladies, la réponse à la fumure. Il existe des lignées de triticale supérieures par un ou plusieurs de ces caractères aux variétés actuellement utilisées, mais également déficientes relativement à certains de ces caractères. S'ils veulent que le triticale devienne concurrentiel par rapport aux autres céréales-grain, les phytosélectionneurs devront s'appliquer à réunir au sein d'une même variété les caractères permettant d'assurer en un lieu donné une production satisfaisante de variétés.

[1]Contribution of the Agricultural Research Service, U.S. Department of Agriculture, and the Agronomic Crop Science Department, Oregon Agricultural Experiment Station, Corvallis, Oreg. 97331.

In the last decade triticale has been evaluated on an experimental basis at many experiment stations in the United States. Briggle (1968) summarized the data available in 1969 and concluded triticale had to be improved before it could compete successfully with wheat. All varieties and experimental lines available in 1969 had serious deficiencies including insufficient cold hardiness for fall planting, excessive lodging, low tillering capacity, reduced seed-set, shrivelled seeds, and poor disease resistance. Since 1969, plant breeders have retested many of the older selections and varieties. A few breeders have been devoting some effort to the development of new experimental lines. A portion of the information collected within the last 2 years by State Agricultural Experiment Stations and the Agricultural Research Service, U.S. Department of Agriculture, was utilized in preparing this report.

Summarization Procedure

The highest yielding triticale was compared with the highest yielding wheat, barley, oat, and rye included as checks in the same trial. Triticale grain, forage, and percentage of protein are expressed in percent of the check varieties. Test weight is stated in kilograms per hectoliter. Information obtained from 13 states was utilized in the preparation of this report.

Grain Production

Triticale produced about 87% as much grain as wheat when yields were averaged over all trials harvested in 1972 and 1973 (Table 1). Triticale planted in the fall produced 18% less grain than wheat, but when seeded in the spring it yielded 18% more grain than wheat. Under irrigation the best triticale line in each trial averaged 27% more grain than wheat.

Advanced experimental lines, selected for adaptation in northern California, from CIMMYT material were grown at Tulelake. The best line produced 27% more grain than the highest yielding wheat check (Table 1). Another group of lines obtained from crosses of cytoplasmic male sterile wheat/rye//6x triticale selected for adaptation in northern Texas was grown at Bushland. The best triticale line produced 11% more grain than the wheat check (Table 1).

Triticale grain yields ranged from 995 kg/ha at one location in Colorado to 11,087 kg/ha at Tulelake, California. In the same trials wheat produced 2283 kg/ha and 10,537 kg/ha, respectively.

Triticale was more competitive when compared with barley. In trials planted in the fall it produced more grain per hectare than barley (Table 1). The relationship was reversed in spring-seeded trials. When compared to barley checks, triticale grain yields ranged from 2186 kg/ha at Comfort, Texas, to 4810 kg/ha in an irrigation trial at Garden City, Kansas. Barley in the same trials produced 1173 kg/ha and 4581 kg/ha, respectively.

Triticale consistently produced more grain than rye (Table 1). It produced less grain than oats in spring-seeded nurseries, but more than oats in the one winter trial included in this summary (Table 1).

Grain Protein and Test Weight

Investigators in Kansas and Texas determined the percent grain protein of triticale lines and cereal checks harvested in 1973 (Table 2). In both states at least one triticale line produced more protein per hectare than the wheat, barley, and rye checks. Because kilograms of protein produced per hectare is the product of grain yield × percent grain protein, the triticale line chosen for comparison with the cereal checks was not necessarily the highest yielding nor the one containing the highest percentage of grain protein.

Triticale seeds are usually shrivelled and test weight is low in comparison with wheat and rye (Table 3). Through hybridization and selection breeders have gradually improved test weight. Simultaneously, grain protein has been reduced in many of the high test weight lines.

At Tulelake, California, one of the new selections produced 9890 kg/ha, which

TABLE 1. Grain yield of the highest yielding triticale included in each trial expressed in percent of wheat, barley, oats, and rye checks in trials conducted in 11 states.

Source	Crop year	No. trials	Wheat	Barley	Oats	Rye
			Fall-seeded			
Arkansas	1972	7	74			
Kansas	1972	10	89	168(1)[a]		130(5)
Kansas, irrigated	1972	2	121	105(1)		130(2)
Ohio	1972	1	76	71		
Oklahoma	1972	1	142	108	134	139
Arkansas	1973	2	67			
California	1973	4	83			
Colorado	1973	19	64			
Kansas	1973	1	75			332
Kansas, irrigated	1973	1	100			208
Louisiana	1973	1	70			
Oklahoma	1973	5	113			171
Texas	1973	4	80	172(1)		
Texas, Bushland	1973	2	111	86		
Average (%)			82	113	134	163
			Spring-seeded			
North Dakota	1972	2	89	74	97	
Ohio	1972	4			67	97(2)
Wyoming	1972	3	109			
Wyoming, irrigated	1972	2	146			
California, Tulelake	1973	1	121			
Indiana	1973	1	140	89	73	
Average (%)			118	79	76	97

[a]Numbers in parentheses are number of trials in which barley and rye were included as checks.

TABLE 2. Grain protein content of triticale, wheat, and rye grown in Kansas and Texas in 1973.

	Triticale	Wheat	%	Rye	%
		Kansas, irrigated			
Grain yield, *kg/ha*	2706	2712	100	1301	208
% grain protein	16.9	14.4	117	16.7	101
Protein yield, *kg/ha*	457	391	117	217	211
Test weight, *kg/hl*	58.7	77.6		68.5	
		Texas, advanced lines			
Grain yield, *kg/ha*	4143	3740	111	4797	86
% protein	17.0	15.7	108	13.4	127
Protein yield, *kg/ha*	704	587	120	643	109
Test weight, *kg/hl*	63.3	72.8		65.3	

weighed 68 kg/hl. Grain protein was not reported. At Bushland, Texas, Porter and Tuleen (1974) have increased test weight of some of their new hybrids without markedly reducing grain protein (Table 4). In Michigan, new winter-hardy triticales have been

TABLE 3. Average test weights of highest yielding triticale line and checks grown in yield trials.[a]

Source	Year	No. trials	Test weights (*kg/hl*)				
			Triticale	Wheat	Barley	Oats	Rye
			Fall-seeded				
Kansas	1972	12	62	76	56(2)[b]		53(7)[b]
Arkansas	1973	1	59	79	58		
Colorado	1973	14	60	80			
Georgia	1973	2	59	70			65
Kansas	1973	6	64	74	57		52
Louisiana	1973	1	58	70			
Texas	1973	6	61	77			
Texas, Bushland	1973	1	63	73	65		
			Spring-seeded				
North Dakota	1972	1	66	77		39	
California, Tulelake	1973	1	70	79			
Indiana	1973	1	58	74	57	46	

[a]*Official test weights*
Wheat 77.4 kg/hl (60 lbs/bu)
Rye 72.2 kg/hl (56 lbs/bu)
Barley 61.9 kg/hl (48 lbs/bu)
Oats 41.3 kg/hl (32 lbs/bu)

Test weight, unofficial
Triticale 67.1 kg/hl (52 lbs/bu)

[b]Numbers in parentheses are number of trials in which barley and rye were included as checks.

developed (Table 4). They have plump seeds and acceptable test weights, but grain protein is low in comparison with the Texas lines. This difference may be in part related to climatic conditions. Daily average temperatures during the grain maturation period are usually lower in the north-central states in comparison with those observed in northern Texas. The genetic potential for grain protein production of the Michigan lines may have been influenced adversely by the relatively low temperatures.

TABLE 4. Relationship between test weight and percent grain protein in winter triticale lines grown in Texas and Michigan in 1973.

Variety or selection	Yield *kg/ha*	Test weight	% grain protein
Bushland, Texas			
27042-45 Triticale	4143	63.3	17.0
27053-53 Triticale	3195	57.1	16.7
Centurk Wheat	3740	72.8	15.7
Lansing, Michigan			
MSU #4 Triticale	4378	68.6	12.4
MSU #2 Triticale	4123	65.2	12.2
6TA610 Triticale	4075	59.7	13.6

Forage Production

Triticale produced slightly more forage per hectare than wheat, barley, oats, and rye in 1972 (Table 5). It was less competitive in the trials conducted in 1973. Unfortunately total dry matter production is less important than is the distribution of production throughout the growing season, rate of regrowth, cold hardiness, and seed production. Specific varieties of wheat, barley, rye, and oats possess more desirable combinations of these characteristics than do the best available triticale lines. Both public and private breeders are devoting considerable effort to the development of forage types that possess the necessary attributes.

TABLE 5. Forage yield of the highest yielding triticale included in each trial expressed in percent of wheat, barley, oats, and rye checks in trials conducted in five states.

Source	No. trials	Wheat	Barley	Oats	Rye
		1972 crop year			
Arkansas	3	115		108	87
Kansas	1	119	142		86
Oklahoma	1	98	97	86	82
Texas	10	105	170(7)[a]	126(9)	112(8)
Texas, irrigated	2	116	95(1)	106(1)	93(3)
Average		108	152	120	102
		1973 crop year			
Arkansas	3	119	70	94	85
Georgia	1	75	95	67	62
Oklahoma	4	94	101(10)	116	82
Texas	11	103	98	103	102
Average		102	98	102	93

[a]Numbers in parentheses are numbers of trials in which barley, oats, and rye were included as checks.

Future for Triticale

Research conducted by the International Maize and Wheat Improvement Center (CIMMYT), Mexico, in Canada, Europe, and the United States indicates the germ plasm for producing high-yielding adapted triticale varieties is available. In the United States most of the plant breeders have been testing lines developed outside the United States or by the Jenkins Foundation for Research, Salinas, California. Public breeders in California, Oregon, and Texas have been devoting some effort to the development of new types. Through hybridization and selection within their new crosses and in CIMMYT material, they have improved self-fertility, grain yield, and test weight. Yet the lines available today are merely building blocks that will be used to produce crosses for another cycle of selection.

During the last few years California breeders have produced new wheat × rye crosses that will be utilized in their breeding program. Porter and Tuleen (1974) are growing male sterile wheats in blocks surrounded by ryes. The best of their new triticale lines were obtained from some of the resulting cytoplasmic male sterile wheat/rye//6x triticale crosses. Some of these lines are self-fertile. They have shown that rye carries gene(s) for restoration of fertility of male sterile wheat/rye hybrids that carry *T. timopheevi* cytoplasm.

If the potential triticale may have as a feed and food is to be realized in the foreseeable future in the United States, far more effort must be devoted to its improvement. Plant breeders throughout the world must be encouraged to follow the CIMMYT policy of making their germ plasm available to other breeders. Through such changes breeders will be able to obtain the genetic variability needed to develop suitable varieties.

Acknowledgments

Data summarized in this report were obtained from State and Federal plant scientists in 13 states: Arkansas, California, Colorado, Georgia, Indiana, Kansas, Louisiana, Michigan, North Dakota, Ohio, Oklahoma, Texas, and Wyoming.

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The Triticale Improvement Program at CIMMYT

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Abstract A triticale program was started at CIMMYT by Dr N. E. Borlaug in 1964 in cooperation with the University of Manitoba. The program was initially funded by the Rockefeller Foundation and in 1971 the Government of Canada undertook complete funding of an expanded program. The major objective was to improve food production and nutrition in the developing countries.

An important advance in triticale improvement occurred with the development of the Armadillo strains. Highly fertile selections from an outcross between triticale and Mexican dwarf wheat contributed greatly to the yield, disease resistance, and nutritional quality of the crop. The plants were day-length insensitive, had an erect growth habit, and one gene for dwarfing.

More resistance to lodging had to be introduced for high production conditions. The sources of dwarfing were the Mexican wheats with the Norin dwarfing genes, Snoopy rye, a dwarf spring rye, and a dwarf triticale possessing a Tom Thumb dwarfing gene developed by Dr Arpad Kiss, Hungary.

New dwarf strains possessing the Armadillo genes for fertility and better resistance to diseases are approaching the yields of the most productive dwarf wheats in Mexico. Reports on triticale performance from international trials indicate that triticale strains are already competitive with other cereals in some regions. Among these are: (1) sandy soils with moderate rainfall in Europe and Mexico; (2) areas of high elevation and high moisture, such as Kenya, Ethiopia, Northern India, and South America; (3) under growing conditions where the night temperatures regularly fall below freezing but rise sufficiently during the day to produce growth.

Most of the reports on quality evaluation indicate that triticale strains are generally higher in protein and have a better amino acid balance than wheat. Bioassays on meadow voles, rats, chicks, and laying hens show that most strains of triticale support good growth and produce a relatively high growth efficiency index. Indications of growth inhibitors have been reported from bioassays studies and from chemical determinations. The importance of these compounds in the grain has not been determined.

Research on utilization of triticale as human food is in progress in many countries. The present strains of triticale do not produce a bread loaf of equal volume and identical texture to that of the best bread wheats. However, in mixtures with bread wheat, and with modification of techniques. bread of satisfactory appearance, taste, and keeping quality can be produced. Research on production of food products in the developing countries has indicated that chapatis, injera, and tortillas of acceptable quality can be made from triticale.

To help utilize triticale for production in developing countries CIMMYT is increasing its effort in training scientists for national programs, assigning staff to specific regions, gathering information on production practices, and distributing seed to cooperators in many countries.

Résumé C'est en 1964 que Monsieur N. E. Borlaug a lancé le programme triticale du CIMMYT, en collaboration avec l'Université du Manitoba. Ce programme fut financé au départ par la Fondation Rockefeller, puis, en 1971, le gouvernement du Canada a pris à sa charge le financement total d'un programme élargi dont l'objectif principal est l'amélioration de la production alimentaire et de la nutrition dans les pays en voie de développement.

La création des souches Armadillo a marqué un progrès important dans l'amélioration du triticale. Des sélections à haute fertilité, obtenues à partir d'un croisement triticale/blé nain mexicain, ont énormément contribué à l'amélioration du rendement, de la résistance aux maladies et de la valeur nutritive du triticale. Les plants obtenus étaient insensibles au rythme nychtéméral, avaient un port érigé et comportaient un gène nanisant.

L'accroissement du rendement a nécessité l'introduction du caractère résistance accrue à la verse. Les transmetteurs du nanisme étaient des blés mexicains, possédant les gènes nanisants Norin, le seigle Snoopy, seigle nain de printemps, et un triticale nain possédant le gène nanisant Tom Pouce, créé en Hongrie par M. Arpad Kiss.

Les nouvelles souches naines possédant les gènes de fertilité Armadillo, en même temps qu'une meilleure résistance aux maladies, ont des rendements voisins de ceux des blés nains les plus productifs du Mexique. Les compte-rendus sur les essais internationaux de triticale indiquent que ces souches de triticale sont déjà, dans certaines régions, concurrentielles par rapport aux autres céréales. Cela concerne en particulier: (1) les régions d'Europe et du Mexique à sol sableux et pluviométrie modérée; (2) les régions d'altitude très humides comme il en existe au Kenya, en Ethiopie, dans le nord de l'Inde et en Amérique du Sud; (3) les régions où la température nocturne tombe régulièrement en dessous du point de congélation mais où la température diurne s'élève suffisamment pour permettre la croissance.

Selon la plupart des compte-rendus d'appréciation qualitative, les souches de triticale ont en général une teneur en protéine et un équilibre des acides aminés supérieurs à ceux du blé. Les essais biologiques effectués sur campagnols, rats, poulets, et pondeuses démontrent que la plupart des souches de triticale sont favorables à la croissance et ont un indice de taux de croissance relativement élevé. L'étude des essais biologiques et les déterminations chimiques ont indiqué l'existence d'inhibiteurs de croissance, mais on n'a pas pu encore déterminer dans les grains l'importance de ces éléments.

De nombreux pays effectuent actuellement des recherches sur l'utilisation du triticale pour l'alimentation humaine. Les souches actuelles de triticale ne permettent pas de réaliser des pains d'un volume et d'une texture identiques à ceux obtenus à partir des meilleurs blés de panification. Il est cependant possible, en mélangeant le triticale à du blé et en modifiant les techniques de panification, d'obtenir des pains d'aspect et de saveur satisfaisants et qui se conservent bien. Selon les recherches sur les produits alimentaires effectuées dans les pays en voie de développement, il est possible de fabriquer à partir du triticale des chapatis, du ndjira, et des tortillas de qualité acceptable.

Afin de promouvoir l'emploi du triticale au stade de la production dans les pays en voie de développement, le CIMMYT accroît ses initiatives visant à la formation de chercheurs pour les programmes nationaux, affecte des cadres à des régions précises, rassemble des renseignements sur les méthodes de production et distribue des semences aux intéressés dans de nombreux pays.

THE CIMMYT triticale program was initiated by Dr N. E. Borlaug in 1964 in cooperation with the University of Manitoba. The project was initially funded by the Rockefeller Foundation but in 1971, the Government of Canada undertook the complete funding for an expanded program at CIMMYT with the University of Manitoba collaborating. The major objective of the triticale program was to produce a crop competitive with other cereals for the developing nations.

The early breeding efforts were focussed on introducing day length sensitivity and disease resistance into triticales from the Mexican bread wheats. A major advance in triticale improvement came in 1968 with the isolation of highly fertile strains, which were labeled Armadillo. Armadillo arose as a spontaneous outcross to a Mexican dwarf bread wheat, and carries genes for day length insensitivity, erect growth habit, improved seed type, and nutritional quality, as well as one gene for dwarfing and resistance to disease. Yield increases of 50–60% were obtained with these strains over the best strains previously available in Mexico.

Improving Resistance to Lodging

Three important sources of genetic dwarfing were used to improve lodging resistance: (*a*) the Norin genes previously used in the bread and durum wheats; (*b*) a dwarf rye "Snoopy" isolated from an open pollinated population of Gator received from Dr Darrell Morey, Tifton, Georgia; (*c*) triticale dwarfs obtained from Dr Arpad Kiss, of Kesckemet, Hungary, possessing Tom Thumb dwarfing genes.

A wide range of plant heights have been obtained among the triticales. We have experienced difficulty in maintaining the high fertility of Armadillo among selections possessing three dwarfing genes. Two gene dwarfs have been produced, such as Cinnamon, that are more resistant to lodging and more productive than Armadillo under conditions of intensive production.

Diseases on Triticales

In Mexico triticales are hosts to the same pathogens that attack wheat and rye. Some of these are more serious on triticale than on wheat, such as yellow dwarf, bacterial stripe, snow mold, and leaf rust. Other pathogens, such as stem rust, stripe rust, scab, loose smut and bunt, find triticale a less suitable but still susceptible host. Diseases, such as ergot, footrot, etc., cause serious damage to triticales in other countries but as yet have not been a problem in Mexico. At the present time control measures are limited to screening for resistance in the Mexican nurseries and in screening nurseries sent to cooperators in numerous countries. A triticale nursery containing about 100 entries and having the best resistance to diseases common in Mexico will be distributed in 1974.

Yield Improvement

The yielding capacity of triticales has improved continuously since the first yield tests were established in Mexico in 1967–68. At that time the best strains produced about one-half as much grain as the Mexican dwarf bread wheats. The development of strains, such as Armadillo and Cinnamon, have improved yields considerably and are now within 90% of those of the best wheat varieties. Further yield increases in triticale are expected with the addition of genes for tillering, additional dwarfing, and better grain test weight.

Broadening the Adaptation

Triticale strains distributed from CIMMYT in the first international trials were generally poorly adapted to conditions outside of Mexico. This was particularly evident in regions above 35° north and south latitude. Selecting in segregating populations at two widely differing environments in Mexico, the Toluca Valley and the Yaqui Valley, has helped broaden the adaptation of the newer strains. Further improvement is expected from utilizing, as parents, selections made by numerous cooperators in repeated cycles of hybridization and selection.

The adaptation of triticale lines to certain specific environments is very encouraging. It appears that triticale strains have specific adaptation to three distinct environments:

(*a*) in areas where temperatures approach or reach the freezing point during the early growth period — such conditions occur in the southern United States and south central Europe during the winter season; (*b*) in high elevation areas found in Ethiopia, Kenya, India, Mexico, and Colombia, where triticale strains are competitive with other cereals; (*c*) in sandy soils under moderate rainfall, which also appear to favor triticale. Reports of favorable performance of triticale on sandy soils have been received from Hungary, Spain, and Mexico.

Nutritional Quality

Dr Eva Villegas is in charge of the chemical and nutritional evaluation of the grain. Screening for better protein quality is done by making a rapid DBC analysis. This identifies lines having either a high protein content or a high per cent lysine. Lines having high DBC values are then evaluated for protein and lysine content.

Bio-assays with meadow voles and chicks have been used as early screening for nutritional quality by Drs Fred Elliott, Michigan State University, James McGinnis, Washington State University, and Reinald Bauer, CIMMYT. Although the voles appeared to have merit as a screening technique requiring small quantities of grain and short feeding periods per assay, they tend to have too wide a variation in growth response among animals and they discriminate against corn in favor of wheat and triticale. Chicks on the other hand require more grain and their protein requirement is too high to be satisfied from cereal grains and must be supplemented. Both meadow voles and baby chicks are sensitive to growth-inhibiting substances in diets and can be used effectively to screen against samples containing such compounds.

Utilization of Triticale

Triticale appears to be suitable as a forage crop or feed grain. A high proportion of the 200,000 acres of triticale grown in the USA is used for grazing or cut as forage for livestock. As a feed grain triticale is equal to, or better than wheat for poultry and probably for swine. Early feeding trials showing adverse effects of triticale as a feed grain may have been influenced by contamination of the grain with ergot.

As human food, triticale does not equal wheat in total extraction of flour nor does it produce bread of equal loaf volume. Utilization research in India and Ethiopia indicates that chapatis and injera of quality equal to that of wheat can be made from triticale. Experiments at CIMMYT have shown that tortillas of acceptable taste and quality can be made from triticale. Some strains of triticale appear to have high enzymatic activity. The commercial distillation of alcoholic beverages from triticale grain is already underway in some countries.

A serious drawback in the current triticales is the shrunken appearance and low test weight of the grain. Screening for better seed quality is being done by visual and mechanical means in the segregating generations.

Agronomic Research

Triticale is now approaching a stage of development where it will enter commercial production in competition with other cereals. There is a need to develop production practices to obtain optimum yields. Information is also required to determine the environmental limitations of the available strains for commercial production. Dr Matthew McMahon joined the triticale staff in 1973 to provide the answers and to develop production techniques. His investigations will also include the tolerance of triticale strains to herbicides, saline soils, sandy soils, and drought conditions. During the next cycle an experiment will be conducted on the competitive position of triticale as a substitute crop for wheat or sorghum as a feed grain for poultry and hogs.

Cytological Research

During the past year, two staff members have been acquired to conduct cytological research on triticales. Dr Arnulf Merker and Mrs Margarita Sosa were both trained on triticale cytology at the Institute of Genetics, University of Lund, under Dr Arne Müntzing. Their work will be directed mainly to the routine determination of chromosome numbers, meiotic stability, and occurrence of aneuploidy in triticale breeding material. Cytological research will also be directed toward the development of techniques for identifying chromosomes of different progenitors so that material from wide crosses can be characterized cytologically.

Triticales on the International Scene

Since the triticale program is directed toward improving food production in developing countries, it is necessary to encourage the utilization of triticales in national programs. This involves: (1) the training of scientists in breeding, production, and extension practices to develop programs in their own countries; (2) the cooperation with other agencies such as IDRC, FAO, etc., who are encouraging the development of triticale production in developing nations; (3) the distribution of triticale strains and segregating material to cooperating institutions and government programs; (4) the development of a package of production practices that can be used as a starting point in the production of triticales where scientific capabilities in national programs are limited; (5) in some countries or regions the assigning by CIMMYT of expatriate staff to help governments establish programs for the commercial utilization of triticales.

Prospects of Triticale as a Commercial Crop in India

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SRIVASTAVA, J. P. 1974. Prospects of triticale as a commercial crop in India, p. 87–92. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract India is very interested in adopting triticale as a new cereal crop, particularly in the rain-fed areas where wheat does not yield well. Early triticale lines were tested at low fertility but did not outyield wheat under rain-fed conditions. Later trials with improved CIMMYT lines planted at higher elevations but in low fertility conditions (pH 6.5) gave higher yields than wheat planted in the same area. The triticale showed high resistance to *Septoria* and powdery mildew and no ergot infection was observed. Observations so far indicate that triticale can be grown as a profitable cereal crop in the Himalayan region of India.

Résumé Les autorités indiennes accorde le plus grand intérêt à l'idée d'adopter le triticale comme nouvelle céréale cultivée, en particulier dans les régions non irriguées où le blé ne pousse pas très bien. De jeunes lignées de triticale ont fait l'objet d'essais en terrains peu fertiles mais elles n'ont pas donné un rendement supérieur à ceux du blé en culture sèche. Les essais ultérieurs effectués avec des lignées améliorées du CIMMYT semées en altitude mais dans des sols à caractère peu fertile (pH 6.5) ont donné des rendements supérieurs à ceux du blé dans ces mêmes régions. Le triticale a manifesté une forte résistance à *Septoria* et à l'oïdium, et l'on n'a pas constaté la présence d'ergot. Les observations effectuées jusqu'ici indiquent que le triticale peut constituer une culture céréalière profitable dans les régions hémalayennes.

INDIA has been interested in the progress being made in research on triticale as a commercial cereal crop, especially in those areas where wheat does not yield well. As it was expected that triticale might withstand the moisture stress and give reasonable yields in the vast rain-fed areas of this country, the early triticale lines developed in Canada and some of the European countries were tried at some locations in the early and mid-1960's. With the reported progress made in improving the grain yield and quality as well as the agronomic characters of triticale, a number of research centres started work on this crop, notably Delhi, Indore, Ludhiana, and Pantnagar in the late 1960's. The triticale lines obtained from different sources, especially CIMMYT, were tested in rain-fed and irrigated conditions. The best lines, on the basis of these tests, were put together and in 1970–71 they were tested at 11 locations along with Kalyansona and the best local checks. The trial was conducted at low fertility (40 kg N, 30 kg P_2O_5, and 20 kg K_2O per hectare) and rain-fed conditions. The trials were spread in the states of Uttar Pradesh, Himachal Pradesh, Gujarat, Madhya Pradesh, Bihar, Rajasthan, Haryana, Punjab, and Delhi. The triticale lines were mostly Armadillo selections, Bronco 90, Bruin 46, and a few local selections. The overall average yields obtained in this trial are presented in Table 1.

TABLE 1. Coordinated triticale trial (1970–71), overall average yield of 11 locations.

	Q/ha
Triticale lines	14.2
Kalyansona (bread wheat)	19.3
Local improved rain-fed variety of bread wheat	19.2

The results obtained from this trial indicated that the triticale lines available at that time were not better yielding than wheat under rain-fed conditions in India.

At Pantnagar, we have been cooperating with CIMMYT's triticale program since 1967. Several selections were made from the lines and segregating populations obtained from CIMMYT and the selected population was planted in 1968 at several locations in the Himalayan region as observation rows with wheat. The triticale lines appeared to grow very well as compared to wheat and barley. Because of their superior performance, they were planted at eight locations in 1969, as observation rows at heights ranging from 1372 to 3049 m (4500–10,000 ft). Again some of the lines appeared to be very promising. In 1970, several selected lines of Armadillo, Bronco 90, and Bruin were planted at an elevation of 2378 m (7800 ft) along with wheat and triticale outyielded wheat. The observation rows were planted in low fertility conditions and the pH was below 6.5 in almost all instances. The triticale lines showed good resistance to *Septoria* and powdery mildew and no ergot infection was observed anywhere.

Dr Chauhan, the triticale breeder at Pantnagar, planted triticale and wheat at several locations in the central Himalayan region during 1971–72 and 1972–73, and at all the locations the triticale lines appeared to do better. He observed that Arm P.M. 116, Arm P.M. 112, Arm P.P.V. 13, and Arm P.M. 114 gave yields of over 4 tons per hectare whereas Kalyansona gave an yield of 2.3 tons per hectare. Our observations so far indicate that the triticale lines could profitably be grown as a cereal crop in the Himalayan region.

To see the performance and adaptability of selected triticale lines in the rain-fed plains of India, we selected six best Armadillo lines, Bronco 90, and a Delhi selection, and, along with Kalyansona (an improved dryland common wheat variety C-306), durum wheat Jori 69, and improved barley variety Ratna, planted at four widely located stations at Durgapura, Powarkheda, Pantnagar, and Pusa. The average yield obtained is summarized in Table 2.

The trial at Durgapura was irrigated. The

TABLE 2. Grain yield, *Q/ha.*

	Durgapura	Pantnagar	Powarkheda	Pusa	Mean
Triticales	16.0	24.8	7.1	9.8	14.4
Kalyansona (common wheat)	25.3	44.8	15.6	16.8	25.6
C-306 (common wheat)	20.1	34.2	20.5	10.5	21.3
Jori C-69 (durum wheat)	16.6	42.5	13.5	11.7	21.1
Ratna (barley)	27.2	34.2	20.1	13.8	23.8

results indicate that these lines do not have yield superiority in the moisture stress plains in India.

Observations taken for plant and grain characteristics are presented in Tables 3–5.

The results indicated that triticale lines tested in these trials were poorer in initial plant stand and shy in tillering compared to wheat and barley. Grain number in spikes was lower as compared to Kalyansona and the seed setting was less than in 70% of the florets. The grains were shrivelled, and the protein content in the grains was not significantly higher compared to Kalyansona. It appears that special effort is required to evolve triticale lines capable of withstanding prolonged soil moisture stress, atmospheric drought, and high temperature common in the rain-fed areas of India. Rye and wheat strains being grown under such conditions may be used to synthesize triticale lines for the above-mentioned conditions.

Under irrigated and high fertility conditions, the performance of some of the triticale lines has been encouraging. In International Triticale Yield Nursery trials (1972–73) conducted at Delhi, Joshi et al. (1973) reported that some of the triticale lines outyielded

TABLE 3. Number of tillers per running meter and number of florets per main earhead.

	Durgapura	Pantnagar	Powarkheda	Pusa	Mean
		Tillers/running meter			
Triticales	72.64	78.89	49.61	48.42	62.39
Kalyansona	84.63	101.50	65.63	71.50	80.82
C-306	90.63	95.00	59.25	56.25	75.28
Jori C-69	77.25	74.63	48.88	49.50	62.57
Ratna	114.63	110.88	72.75	21.37	94.91
		Florets/main earhead			
Triticales	69.75	64.73	65.75	47.18	61.85
Kalyansona	75.45	66.70	56.25	50.20	62.15
C-306	52.95	48.40	60.00	41.95	50.83
Jori C-69	60.45	59.40	56.10	33.47	52.36
Ratna	56.35	49.00	57.75	37.45	50.14

TABLE 4. Number of grains per main earhead and fertility (%).

	Durgapura	Pantnagar	Powarkheda	Pusa	Mean
		Grains/main earhead			
Triticales	44.73	47.28	39.25	31.65	40.73
Kalyansona	59.30	56.75	46.55	39.17	50.44
C-306	45.35	41.88	51.50	34.75	43.37
Jori C-69	43.10	41.93	39.35	19.80	36.05
Ratna	49.60	43.85	52.20	33.25	44.73
		Fertility (%)			
Triticales	62.97	73.57	59.02	66.77	66.33
Kalyansona	77.02	80.42	79.75	77.72	78.73
C-306	85.73	84.10	85.15	81.86	84.21
Jori C-69	70.64	70.57	73.11	55.68	67.50
Ratna	86.35	89.33	90.36	88.11	89.54

TABLE 5. 1000 Kernel weight and protein (%).

	Durgapura	Pantnagar	Powarkheda	Pusa	Mean
Triticales	29.92	40.33	37.55	34.65	35.61
Kalyansona	31.22	36.28	38.05	35.17	35.18
C-306	37.99	46.74	45.77	38.04	43.14
Jori C-69	39.45	58.35	56.35	41.04	48.79
Ratna	41.73	46.64	47.84	41.65	44.46
		Protein (%)			
Triticales	14.60	14.82	16.10	11.38	14.23
Kalyansona	13.91	14.41	15.00	12.22	13.88
C-306	11.28	11.42	12.15	9.25	11.03
Jori C-69	8.71	13.49	14.00	12.79	12.25
Ratna	7.97	9.63	8.89	6.65	8.29

best common wheat varieties. The performances of the best five entries in this trial are presented in Table 6.

The same nursery was planted at Ludhiana, under high fertility and irrigated conditions and Gill et al. (1973) reported that a number of triticale entries outyielded bread wheat variety Kalyansona. The yields obtained at Ludhiana are presented in Table 7.

Kalyansona was heavily infected by brown rust. These and other results obtained from irrigated and well-fertilized trials indicate that some of the triticale lines hold the promise of performing as well as, or even better than, the best bread wheat varieties, at least in those areas where they have been listed.

The primary use of triticale in the Indian subcontinent and particularly in the Himalayan region will be in the form of "chapati." Extensive tests were done to compare chapati-making properties of triticale flour with that of wheat (Fig. 1). The Armadillo lines were

TABLE 6. Performance of best five entries in the International Triticale Yield Nursery (1972–73) at Delhi.

Strain	Yield (*Q/ha*)
Maya II Arm-S	39.2
Inia Arm-S	36.3
Inia-Gra-Arm	36.0
Pitic (common wheat)	35.3
Kalyansona (common wheat)	34.4

TABLE 7. Performance of some of the triticale strains for grain yield in the International Triticale Yield Nursery at Ludhiana (1972–73).

Strain	Yield (*Q/ha*)
Cinnamon	58.0
Arm-S (S. No. 12)	55.1
Inia-Arm-S (S. No. 7)	52.9
Arm-S 105	52.2
Inia-Gra-Arm-S	50.7
Inia-Arm-S (S. No. 17)	50.7
Arm-S (S. No. 11)	49.3
Tcl Maya II Arm-S	48.5
Kalyansona	32.6

compared with wheat variety C-306. The triticale flour from the selected Armadillo lines was whiter as compared to C-306 and to some extent behaved like soft wheat flour (Fig. 2). However, it absorbed less water but the chapati puffing quality was comparable and was sweeter than that made from C-306. The triticale chapati was slightly leathery as compared to that of C-306. The triticale and wheat flour was distributed to a number of families for comments on the chapati-making quality. The laboratory and consumer tests indicated that triticale flour is acceptable for chapati making.

Encouraged by the performance of triticale at limited locations in the central Himalayan region, we wish to test the best available triticale line in the western and central Himalayas.

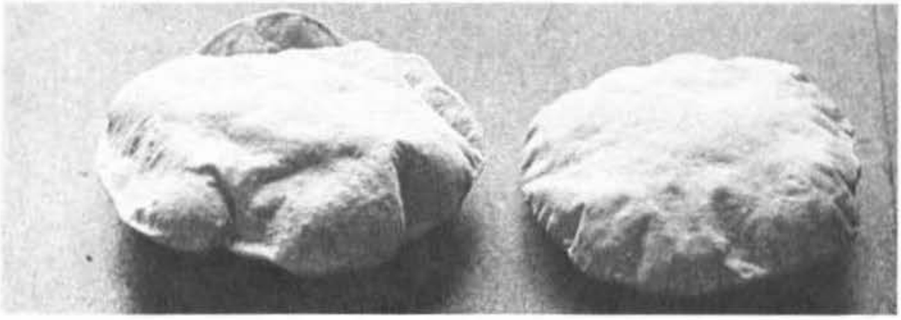

FIG. 1. Chapati made of triticale (*left*) and wheat (*right*).

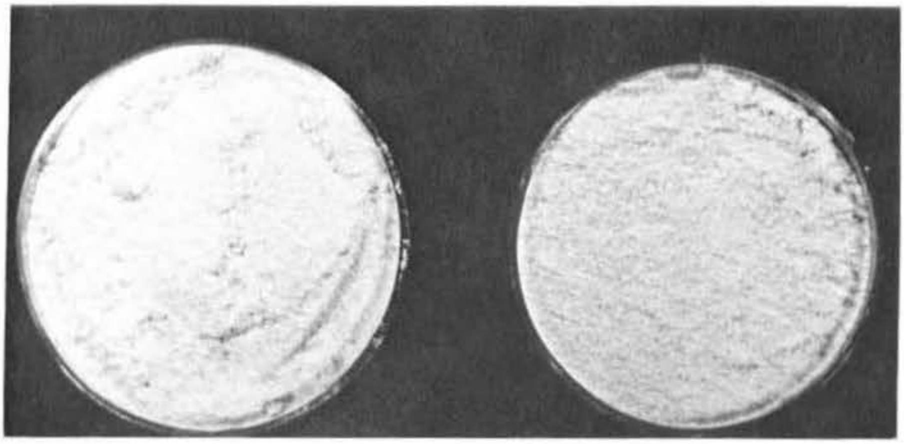

FIG. 2. Triticale flour (*right*) from the selected triticale lines is better in appearance than the wheat flour (*left*).

Approximate areas of the Himalayan region including Afghanistan where triticale can be tried as a commercial crop for human consumption are given below:

Region	*Population*
Western Himalayas	18,913,173
Central Himalayas	12,374,185
Outer Himalayas including Afghanistan	14,000,000

The different Himalayan regions will include the following areas:

Western Himalayas
- (I) Punch & Jammu
- (II) Pir Punjal range
- (III) Vale of Kashmir
- (IV) Main Himalayan mass
- (V) Gilgil-Hunza
- (VI) Laddakh
- (VII) Karakoram

Central Himalayas
- (I) Himachal Pradesh
- (II) U.P. Hills
- (III) Nepal
- (IV) Parts of Tibetan Plateau

Eastern Himalayas
- (I) Kosi Basin–Eastern Nepal
- (II) Darjeeling–Sikkim
- (III) Bhutan & Assam Himalayas

In the Western Himalayas total precipitation is low and it increases eastwards. Similarly temperature is lower in the Western Himalayas and it decreases eastwards. In the Western Himalayas the precipitation is higher in January–March than in monsoon months

(June–September), which means winter rains during crop growth. The reverse is true in the Eastern Himalayas. In the Valley of Kashmir annual rainfall is 25 inches whereas in Laddakh it is 3–4 inches. In Himachal it is 60 inches, in U.P. Hills 70 inches, and in the Eastern Himalayas it is 125 inches. The soil is predominantly acidic (pH ranging from 4.5 to 6.5). In a few areas the soil is alkaline.

This whole area provides a special challenge with respect to providing food as it is a food-deficient area. The people are poor and nutritionally deficient. The staple food is millets, maize, wheat, barley, and rice. The soil will remain acidic for years to come, the fertilizer availability will remain scarce, and the crop will be grown under rain-fed conditions. The advance wheat production technology cannot be adopted in large areas except in the valleys. There is a definite need for a cereal that can give reasonable yields under these trying conditions without demanding sophisticated production technology and higher inputs, and as far as I can see triticale fits the requirement.

The ergot problem needs to be studied carefully in this area. The well-filled grains of improved triticale lines may remove the problem of early viability loss and poor germination. There is need for extensive tests with the best triticale lines in the whole area extending from Afghanistan to Nepal. At the same time, seed of superior lines needs to be multiplied somewhere in this area, so that in a year or so seed of these varieties can be distributed to the farmers for commercial evaluation.

There is very little information regarding suitable cultivation practices for triticale in the hills. We plan to conduct agronomic trials in these areas this year to give some guidelines in this respect.

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Triticale Breeding Experiments in India

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SISODIA, N. S. 1974. Triticale breeding experiments in India, p. 93–101. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Work was started in 1971 to develop improved lines of triticale specifically adapted to growing in India's rain-fed season (August–December). Germ plasm of triticale and rye was initially supplied by the University of Manitoba, and additional germ plasm has come from CIMMYT. Under rain-fed conditions triticale grows well in areas having a cooler climate and frequent rain during the growing season. Where triticale must mature on stored soil moisture, performance so far has not been satisfactory. Yield data on 1971–72 and 1972–73 trials are given both for rain-fed and irrigated conditions. Results of studies on floret fertility, number of spikelets, seeds/spike, kernel type, and protein content are also available.

Résumé Dès 1971, des travaux sont entrepris dans le but de créer des lignées de triticale améliorées spécialement adaptées à la culture en saison des pluies aux Indes (août–septembre). C'est l'Université du Manitoba qui a fourni le premier matériel génétique de triticale et de seigle, auquel s'est ajouté celui venant du CIMMYT. La croissance du triticale cultivé à sec est bonne dans les régions à climat frais et à pluies fréquentes au cours de la saison de végétation. Les résultats n'ont jusqu'à présent pas été satisfaisants dans les régions où la maturité du triticale doit s'accomplir grâce à l'eau stockée dans le sol. Le texte fournit des données sur les rendements des essais de 1971–72 et de 1972–73, à la fois en culture sèche et à l'irrigation. Il mentionne également les résultats des études sur la fertilité des fleurs, le nombre d'épillets, le rapport grains/épis, les types de grains et la teneur en protéines.

THE triticale improvement program in India was undertaken in 1970 at Indore Campus of the Jawaharlal Nehru Agriculture University, M.P., in close cooperation with the University of Manitoba, Winnipeg, Man., Canada. The main objectives of this program are to develop improved varieties suitable for growing under irrigated and rain-fed conditions that have desired grain quality. In 1971 work was started to develop varieties adapted for growing during autumn (August–December) under rain-fed conditions, which is a more favorable season in terms of soil moisture.

Indore is situated at 22°43′N latitude and 76°54′E longitude at an elevation of 600 m in the State of Madhya Pradesh. The average maximum and minimum temperatures and rainfall for July–April are presented in Fig. 1. The monsoon season extends from late June to the end of September. During this period

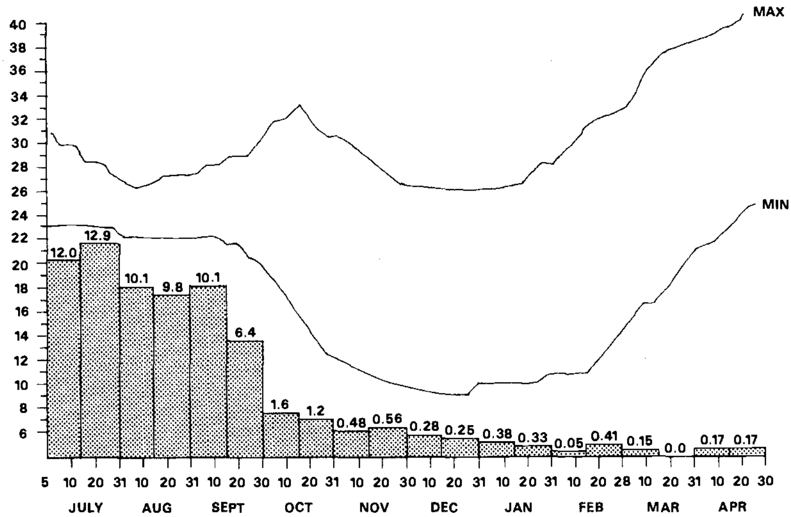

FIG. 1. Average maximum and minimum temperatures (°C) and rainfall (cm) for the months of July to April at Indore.

about 764 mm of rainfall are received. The crop season extends from mid-October to the end of March. The rains are infrequent during these months, averaging once in 4 years. The crops, therefore, have to mature on the stored soil moisture under rain-fed conditions.

Experimental Approach

Introduction and Evaluation of Germ Plasm

A large collection of germ plasm of triticale and rye was initially introduced from the University of Manitoba. Additional introductions from Manitoba and CIMMYT are being added and evaluated on a regular basis.

Breeding Program

Besides making crosses among improved hexaploid triticales, the methods proposed by Sisodia and McGinnis (1970*a*) were followed in order to introduce new wheat and rye germ plasm in the breeding populations. To develop triticales of amber-white seed colour, a white-seeded triticale strain synthesized from the cross 4B909 × 2D53 at the University of Manitoba has been used extensively in the hybridization program. When making crosses, particular attention has been given to incorporating hexaploid wheat cytoplasm in triticales following the hypothesis put forward by Sisodia and McGinnis (1970*b*).

In addition to selection for desired agronomic attributes, special emphasis has been given to improving kernel type. The F_2 generation is grown under irrigated conditions and desired plants are selected. Individual plants are rigidly screened for seed type and graded in a scale of 1 to 5 (1 refers to very poor and 5 to very good kernels, almost comparable to wheat). The F_3 generation is evaluated under rain-fed conditions in a contiguous plot design and includes a wheat check planted after every 10 plots. Rigid selection is made visually in F_3 and later generations on individual spike basis for kernel development. At a later stage, promising strains are subjected to seed density evaluations in a thin paraffin liquid (Klassen et al. 1971).

Development of Autumn Triticales for Growing during August–December

A large number of genotypes were screened by repeated plantings around 15 August, 1 September, and 15 September to identify genotypes adapted to this growing season. In addition, segregating populations were planted for a selection of desired plants in an attempt to develop varieties specifically suited to this growing season. Starting in 1973, the breeding program was oriented toward producing two generations in a year (August–December and January–April) to expedite the breeding program and to introduce wider adaptability in the material. This involves making crosses in November–December, advancing to F_2 generation in January–April, growing F_2 in August–December, and F_3 in January–April. Material thus developed will be tested during the August–December and October–March growing seasons.

Experimental Results

Yielding Ability

The results of triticale strains tested during 1971–72 and 1972–73 are presented in Table 1.

(*a*) *Under rain-fed conditions*: Trials were conducted at three locations at fertility levels of 40:30:0 N:P:K kg/ha.

Except at Dehradun, performance of triticale under rain-fed conditions had not been satisfactory. The yield of a top triticale strain was 970 kg/ha compared to 1580 kg/ha of the wheat check Narbada-4. In a trial at Indore in 1972–73, top triticale strains yielded 860 kg/ha compared to 776 kg/ha for the wheat check. At Dehradun, the top triticale strain gave 4533 kg/ha. However, the growing conditions at Dehradun are very different from those in the plains, where the crop has to be mainly raised on stored soil moisture. Dehradun is situated at an elevation of approximately 914.6 m (3000 ft). The growing season is relatively cooler and longer (about 150 days). During the crop season of November–April, frequent rains total about 200–250 mm.

(*b*) *Under irrigated conditions*: The trials were generally conducted at fertility levels of 100:60 N:P kg/ha. Potash was applied whenever soil tests showed it was deficient.

Triticale strains tested so far have given satisfactory performance under irrigated conditions. The highest yield obtained was 4919 kg/ha compared to 3614 kg/ha for the wheat check. At other locations, the yield of top triticale strains ranged from 3480 to 2060 kg/ha. In addition to these results, in a preliminary testing of 45 new triticales at Indore in 1972–73 the average yield was 3645 kg/ha and the maximum yield 6400 kg/ha. In the 1972–73 Indore trials the later-maturing varieties were damaged by frost around 28–30 January and the yields were affected. The wheat check

TABLE 1. Yield of the best triticale strains compared with the wheat checks under irrigated and rain-fed conditions (kg/ha).

	Irrigated				Rain-fed			
	Triticale				Triticale			
Source	No. strains	Avg yield	Yield of top strain	Wheat checks	No. strains	Avg yield	Yield of top strain	Wheat checks
Indore, 71–72	14	2718	3443	2023	16	859	969	1355
Indore, 72–73	14	2719	3196	3309	8	694	860	776
Kasturbagram, 72–73	13	1729	2099	–	–	–	–	–
Powarkheda, 72–73	16	1310	2060	2060	13	792	970	1580
Jabalpur, 72–73	16	1583	2923	2510	–	–	–	–
Dehradun, 71–72[a]	–	–	–	–	9	3479	4533	–
Ludhiana, 72–73[a]	23	–	4919	3614	–	–	–	–
Delhi, 72–73[a]	27	–	3480	3620	–	–	–	–

[a]Data were kindly provided by Dr K. D. Koranne from Dehradun, Dr G. S. Sandha from Ludhiana, and Dr M. G. Joshi from Delhi.

Kalyan sona escaped frost damage since it flowered around 15 January.

Floret Fertility, Number of Spikelets, and Seeds/Spike

Results of 66 strains examined under irrigated conditions and 16 examined under rain-fed conditions are presented in Table 2. Percent floret fertility under irrigated conditions in different strains ranged from 75.5 to 98.3 compared to 92.5 to 95.9 for that in the wheat check cult Kalyan sona. The lower floret fertility during 1972–73 trials may have been due to frost damage as mentioned earlier. Under rain-fed conditions, the floret fertility level is rather low (average 75.2%) and the highest fertility recorded was 84.9%. Number of spikelets among different strains under irrigated conditions ranged from 16.6 to 37.3 compared with 18.4–19.8 in the wheat check. Seeds/spike in triticale ranged from 40.8 to 83.3 compared with 52.0 to 56.0 in Kalyan sona. Under rain-fed conditions, number of spikelets and seeds/spike in triticale averaged 20.2 and 32.4 compared with 13.4 and 30.1, respectively, in the wheat check.

Kernel Type

Out of a total of 45 improved strains classified visually for kernel type, 19 had a score of 4, and 5 had a score of 5. Similarly, in grain density estimates, out of 38 lines tested, 18 had 1.21, and 2 had 1.25 grain density. The grain density of wheat cult Kalyan sona was 1.31. In general, grain density estimates agreed well with the visual ratings.

With respect to seed size, considerable variability existed among the triticale strains examined (Fig. 2). Out of 88 strains examined, 33 had 40–49 g and 38 had 35–40 g per thousand kernel weight.

Protein Content

Results of 70 improved strains analyzed for protein content are presented in Table 3. Protein content varied from 9.1% in five strains to 14.3% in one strain compared to 12.3% in the wheat cult Kalyan sona.

A number of individual head progenies from an EMS (ethyl methane sulfonate)-treated and control population of a triticale strain 6TA204 were analyzed to see if EMS treatment induced variability of protein content. The results are presented in Fig. 3. The protein content in controls ranged from 9.8 to 14.9% (average 12.30%) and in treated populations from 9.8 to 16.3% (average 12.63%). Whether the high protein content of 16.3% is mutagen-induced is currently under investigation.

TABLE 2. Range in percent (averages in parentheses) floret fertility, number of spikelets, and seeds/spike in triticales compared with wheat checks.

	Triticales				Wheat checks		
Source	No. strains	Floret fertility	No. spikelets	Seeds/spike	Floret fertility	No. spikelets	Seeds/spike
Irrigated conditions							
Indore, 71–72 (IETI)	14	85.5–98.3 (92.1)	21.0–32.0 (26.2)	45.0–71.9 (61.3)	95.9	19.8	56.0
Indore, 71–72 (TP)	14	81.0–96.9 (89.3)	22.0–34.0 (27.2)	59.3–83.3 (68.0)	–	–	–
Indore, 72–73 (IETI)	20	75.5–85.8 (81.4)	16.6–33.7 (29.5)	40.8–64.5 (55.1)	93.4	18.8	53.6
Indore, 72–73 (TYTI)	18	80.4–89.9 (85.2)	17.6–37.3 (24.1)	43.3–63.9 (45.1)	92.5	18.4	52.0
Rain-fed conditions							
Indore, 71–72 (IETD)	16	65.4–84.9 (75.2)	17.2–25.5 (20.2)	26.2–41.4 (32.4)	92.6	13.4	30.1

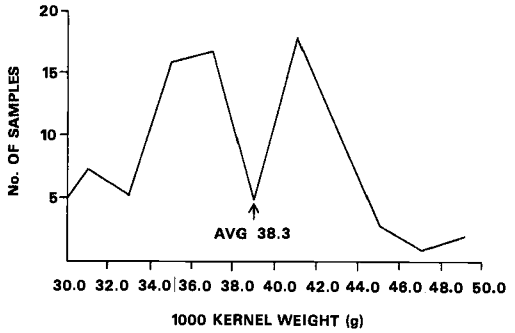

FIG. 2. Variability in thousand kernel weight (g) among improved triticale strains.

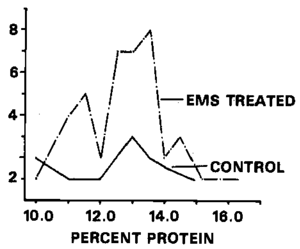

FIG. 3. Variability for protein content in an EMS (ethyl methane sulfonate)-treated and control population of a triticale strain 6TA204.

TABLE 3. Variability for protein content in improved strains of triticale (13.5% moisture, N × 5.70).

% protein	No. samples
9.1	5
9.9	13
10.8	24
11.6	18
12.5	7
13.4	2
14.3	1
12.3	Wheat cult Kalyan sona

Individual head progenies from some lines with high and low protein content were examined to see if variability for protein content still persisted (Table 4). Out of seven lines examined, two lines had a range in protein content from 11.1 to 15.0. In the remaining lines the variability was approximately 2%.

Development of Autumn Triticales

During 1971 and 1972, 230 strains were screened by repeated plantings between 15 August and 15 September. From the material screened in 1971, 23 strains have been selected for further evaluation (Table 5), and the highlights of the results are summarized below.

(*a*) Considerable variability in maturity period and important yield components, viz. tiller number, seeds/spike, and 1000 kernel weight, existed among different lines.

(*b*) Material of Mexican origin, in general, flowered too early within 40–45 days and had poor tillering and smaller spikes. Lines flowering in approximately 60–75 days had good tillering and satisfactory spike length.

TABLE 4. Variability for protein content among different head progenies of selected line of 6TA204 (13.5% moisture, N × 5.70).

Parental line		% protein in the progenies	
Designation	% protein	Range	Avg
6TA204–48	16.3	11.5–15.0	12.5(6)[a]
6TA204–11	15.2	11.1–15.0	12.6(6)
6TA204–139	14.4	11.1–13.0	12.0(5)
6TA204–168	14.2	11.1–13.0	11.9(3)
6TA204–24	14.1	12.1–14.0	13.0(4)
6TA204–183	13.4	10.1–12.0	11.0(6)
6TA204–98	10.7	12.1–13.0	12.9(3)

[a]Number of progenies examined.

TABLE 5. Performance of 23 selected strains of triticale planted on 25 August (D_1), 8 September (D_2), and 20 September (D_3).

Character	D_1		D_2		D_3	
	Avg	Range	Avg	Range	Avg	Range
Days to head	72.6	62–85	80.1	62–98	90.5	76–96
Days to mature	127.7	112–133	137.0	127–144	139.6	131–144
No. tillers	3.5	2.0–6.6	4.3	2.4–7.6	5.7	2.6–9.4
Seeds/spike	26.4	17.5–34.5	31.0	21.0–38.7	31.7	22.7–35.0
1000 kernel weight (*g*)	36.3	32.0–40.5	38.3	30.4–51.4	39.0	33.0–46.7
Yield of 10 spikes (*g*)	9.5	6.0–14.0	12.3	8.8–15.9	12.3	9.9–14.4

(*c*) A number of lines had good vegetative growth including spike length. However, a varying degree of sterility was observed among plants within a strain that was normally fully fertile during the traditional season.

(*d*) Rust diseases were not observed. Other foliar diseases such as *Helminthosporium*, *Septoria*, and *Alternaria* were present. However, some appeared to be disease-free.

Discussion

Yielding Ability

Concurrent with the improvement in floret fertility and kernel development in triticales (Fig. 4), there has been a considerable improvement in yielding ability. On the basis of results obtained in this study and reported elsewhere (Zillinsky and Borlaug 1971), strains giving comparable yield to the commercial wheat varieties under irrigated conditions are available. Crop husbandry information in triticales, namely optimum plant population, optimum plant spacing, depth of sowing, optimum fertilizer doses, etc., is not readily available and appears to be a limiting factor in realizing the fullest yield potential.

Under rain-fed conditions, triticales appear to perform well in specific areas having relatively cooler climate and receiving frequent rains during the crop season. Under conditions where the crop has to mature mainly on stored soil moisture, performance of strains tested so far has not been satisfactory. Some possible reasons are:

(*a*) *Poor development of roots in heavy soils resulting in considerable mortality of fully grown plants* — The soils in Indore region are heavy, containing 50–60% clay. In these heavy soils the roots usually grow near the surface, resulting in poor plant anchorage and ultimately in plant mortality. Rye is better adapted to lighter soils and it may be that this characteristic is also inherited in triticales.

(*b*) *Inability to tolerate stress conditions (temperature and moisture) resulting in partial floret sterility and poor kernel development* — Reduction in fertility of 10–25% has been observed under rain-fed conditions (Table 1). The stress normally appears around mid-January when the plants are in anthesis. Ripening takes place when temperatures start to rise in February, resulting in poor kernel development.

Unlike established crop species, the genetic system in triticale is relatively new and has been developed so far on a narrow genetic base. The crop, therefore, appears to lack stability and adaptation (Anon. 1970–71). There is a need to enlarge the genetic base and expedite the evolutionary processes by extensive and collective efforts under different ecological conditions. Use of artificial mutagenesis may also prove advantageous in expediting the evolutionary processes. In the synthesis of triticale, mostly rye strains of North American origin have been utilized. Photo-neutral and autogamous strains of rye

FIG. 4. An improved strain of triticale having good floret fertility and kernel development.

may prove more useful in increasing stability and adaptation. The rye germ plasm needs to be screened for identifying more drought-resistant strains with extensive roots, particularly under heavy soil conditions. Such strains should be utilized for the development of triticales particularly suitable for growing under rain-fed conditions.

Kernel Type

In India, consumers buy whole grains and there is a strong preference for large, plump, white-amber kernels. Therefore, special emphasis for improving kernel type has been given in the breeding program. Following rigid recurrent selection on an individual spike basis for well-developed kernels, considerable progress has been made, resulting in a few lines having kernels almost comparable to wheat. Thus, whatever may be the reasons for poor kernel development in triticales, selection for this character had been effective, indicating that genetic factors are important in kernel development. Improvement in kernel development has also been reported following radiation treatment by Sanchez-Monge (1968) and Joshi et al. (1973) and needs to be investigated further.

Our experience in the past has been that large kernel size in triticales was often associated with partial floret sterility or shrivelled kernels, or both. A number of fully fertile strains with 40–49 g per thousand kernel weight and reasonably developed kernels have been developed (Fig. 2), indicating that it would be possible to maintain large kernel size in improved strains of triticale.

Protein Content

Following improvement in yielding ability in triticales, there appears to be a decline in protein content. Of the 70 improved strains examined, only three had higher protein content than the wheat check Kalyan sona (Table 3). In triticale breeding, so far no consideration for protein content has been given in the choice of parents, and unless this is done it may not be possible to maintain high protein content. Variability for protein content in rye germ plasm needs to be studied to identify high protein strains for use in the synthesis of triticales.

Considerable variability in protein content (9.8–16.3%) was observed among different head progenies of a triticale variety (Fig. 3). Normally in a routine breeding program, no selection for protein content is practiced and protein estimations are usually made at a later stage of development of a variety. Thus, a variety otherwise homogeneous is expected to be heterogeneous for characters that have not been selected. Accordingly, protein content in a variety may represent an average estimate of high and low protein genotypes. Selection for high protein content in an otherwise high-yielding variety, therefore, is expected to be effective.

Development of Autumn Triticales

In the State of Madhya Pradesh, rain-fed wheat occupies an area of about 2.8 million ha, which constitutes approximately 94% of the total area under wheat in the state. The general practice of rain-fed wheat cultivation is to take only one crop in a year from mid-October to the end of March. In many areas, usually there is no rain during this period and the crop has to mature on stored soil moisture. The yields are, therefore, very poor, averaging about 5 q/ha. The production suffers further under conditions of partial failure, or an early end of the monsoon (as happened in 1972), or both.

Most of the rainfall is received during the monsoon (late June to end of September). Thus, July to December is a more favorable season in terms of soil moisture. However, wheat is not grown during this season mainly because of relatively warmer temperatures and wet soil conditions. Triticale, being a combination of two distinct plant species, and of very recent origin, provides a unique opportunity to develop plant types better suited for growing in a season and in areas where wheat or rye, or both, will not grow successfully. The results obtained so far have been encouraging (Table 5). However, because of lack of stability and adaptation in triticales, it will be necessary to develop specifically adapted varieties. Suitable varieties for growing during this season have to meet certain requirements as follows:

(*a*) *Thermal insensitive or processing relatively higher thermal requirements* — The average maximum and minimum temperatures at Indore for the period July–April are given in Fig. 1. There is not much difference in the maximum temperatures during August–September (range 27.6–30.4°C) and November–December (range 29.6–26.3°C), but the minimum temperatures drop rapidly starting around mid-October to 9.4°C in December. In comparison, minimum temperatures during August–September remain around 21.9°C. Suitable varieties for this season, therefore, should be adapted to a temperature range of 21–31°C compared to 10–31°C as prevalent during the traditional season.

(*b*) *Ability to grow under wet-soil conditions* — At Indore, almost two-thirds of the total rainfall averaging about 500 mm occurs before 15 August and about 270 mm between 15 August and 30 September. The earliest period suitable for sowing is therefore around 15 August.

(*c*) *Flexibility in sowing time* — Monsoon uncertainties may not permit sowing operations to be completed within a narrow period. The varieties, therefore, should be adapted for planting over a wide period between 15 August and 15 September.

The prevailing concept, that warmer temperatures result in poor tillering and poor plant growth, was not found to be true for all the varieties examined. In the case of wheat, which has a longer vegetative phase, better tillering and extensive roots result. For induction of flowering, i.e., change from vegetative to reproductive phase, a variety should meet its photoperiod requirements unless it is photo-insensitive. Assuming that triticales would behave like wheat, by selecting appropriate photo-sensitive genotypes it would be possible to have good tillering despite higher temperatures.

Acknowledgments

The author expresses his appreciation to the University of Manitoba, Winnipeg, Man., Canada, for providing triticale germ plasm and offering a Visiting Professorship for a 3-month period in 1970 and 1971, which assisted in expediting the program in India. Material has been received from CIMMYT, Mexico, which is duly acknowledged. The protein analysis was done by Dr A. D. Deodhar, Cereal Chemist, at the Jawaharlal Nehru Agriculture University, India, and Dr W. Bushuk and his associates at the University of Manitoba. Their help is gratefully acknowledged.

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Triticale Research Program in Iran[1]

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VAHABIAN, M. A. 1974. Triticale research program in Iran, p. 103–105. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Triticale cultivars have been tested in Iran since 1963, and yield trials have been conducted since 1968 at the central cereal breeding station at Karaj. No true breeding work has been initiated to date.

In yield performance trials between 1970 and 1973, none of the triticales were significantly superior to the improved wheat varieties, although some of them had a higher protein content. The triticales had low productivity because of their low tillering capacity, even in trials where there was excellent stand establishment.

Mexican triticales were superior in height and lodging resistance and also had better fertility when compared with Californian lines. The Californian lines, however, were superior in winter-hardiness.

Résumé Certains cultivars de triticale ont fait l'objet de testages en Iran depuis 1963 et l'on a effectué depuis 1968 des essais de rendement à la station centrale de sélection des céréales de Karaj. Jusqu'à ce jour, aucun vrai travail de sélection n'a été entrepris.

Aucun des triticales soumis à des essais de rendement entre 1970 et 1973 ne s'est révélé supérieur aux variétés de blé améliorées, bien que certains d'entre eux aient des teneurs en protéine plus élevées. La productivité des triticales s'est avérée faible du fait de leur capacité de tallage réduite, bien que les peuplements se soient révélés excellents au cours de certains essais.

Les triticales mexicains se sont révélés supérieurs sur le plan hauteur et résistance à la verse, en même temps qu'ils avaient une fertilité meilleure comparativement aux lignées californiennes. Ces dernières se sont cependant avérées plus résistantes aux rigueurs de l'hiver.

TRITICALE cultivars have been tested in Iran since 1963; however, no emphasis was placed on this program at the beginning except for having this new crop available for observation. Further improvements were essential to make it a practical commercial crop.

Yield trials have been conducted since 1968 at the central cereal breeding station at Karaj, Iran. In addition to all the Interna-

[1]Presented in brief at the Symposium by Gerbrand Kingma.

tional Triticale Yield Nursery (ITYN) lines, some advanced lines and segregating material from the Jenkins Foundation have been tested; however, no true breeding work has been initiated to date.

In the first year of ITYN (1970), the best triticale varieties were Armadillo 133 and Armadillo 135, which yielded 77 and 79%, respectively, when compared with a locally improved wheat variety. The only entry that outyielded the check was Pitic 62, which yielded 2.34 t/ha compared with 2.06 t/ha for the wheat check variety.

In 1971 in ITYN, some triticale varieties were substituted with more productive varieties but still none of them have outyielded the locally improved wheat varieties. The best triticale varieties were Armadillo 136 and Armadillo 133, which yielded 77 and 73%, respectively, when compared with the check.

In the same year another trial with larger-sized plots and more replications but with almost the same varieties was conducted. Emphasis was placed on proper soil fertility levels and proper management. The best triticale varieties were Armadillo 130 and Armadillo 157, which yielded 4.7 and 4.6 t/ha, respectively, which corresponded to 86 and 84% of the check.

In 1972 a larger trial was conducted with some Mexican and some Californian triticales as well as some winter and spring wheat varieties. The performance of the better wheat and triticale varieties was evaluated (Table 1).

The same trial was repeated in 1973 but none of the varieties outyielded the check variety, which produced 5.58 t/ha.

The yield performance of a few triticale lines over a period of several years was compared with their respective checks (Table 2).

TABLE 1. Comparison between selected triticale and wheat varieties in the B-test in 1972 at Karaj Station, Iran.

Variety	Frost damage[a]	Stripe rust[a]	Height (*cm*)	1000 kernel wt	Yield (*t/ha*)	% check
Dayhim (wheat check)	MR	0	118	–	6.3	100
Ommid (wheat check)	R	50S	146	–	4.4	69
Mexipak (wheat check)	MR	10S	101	46	5.3	84
6 TA 419 (trit.)	R	0	126	48	6.6	104
6 TA 421 (trit.)	MR	0	157	44	6.0	95
6 TA 501 (trit.)	R	0	142	–	6.9	109
Armadillo 138 (trit.)	MR	0	123	41	5.5	87
Armadillo 136 (trit.)	MR	0	133	39	5.9	94
Winter triticale (trit.)	R	0	143	52	6.2	99

[a]R = resistant; MR = moderately resistant; S = susceptible.

TABLE 2. Yield performance of selected triticale lines in different years in Iran.

Variety	1970		1971a		1971b		1972		1973		Average	
	Yield (*t/ha*)	% check	Yield (*t/ha*)	% check	Yield (*t/ha*)	% check	Yield (*t/ha*)	% check	Yield (*t/ha*)	% check	Yield (*t/ha*)	% check
Armadillo 133	1.59	77	4.43	73	4.29	78	4.37	69	4.22	76	3.78	74.6
Armadillo 135	1.62	79	–	–	4.11	74	4.24	67	–	–	3.32	73.3
Armadillo 136		–	4.67	77	–	–	5.97	94	3.55	64	4.73	78.3
Armadillo PM-13		–	4.32	71	–	–	5.48	87	3.74	67	4.51	75.0
6 TA 419		–		–	–	–	6.60	104	5.52	99	6.06	102
6 TA 421		–		–	–	–	6.01	95	5.38	96	5.69	95.5
6 TA 501		–		–	–	–	6.89	109	4.99	89	5.94	99

Though none of the triticales was significantly superior to the improved wheat varieties, some of them did have a higher protein content per unit.

The reason for the lower productivity of the triticales, in addition to sterility, was their low tillering capacity, even in trials where there was excellent stand establishment.

A Mexican barley variety, Apizaco, was also included in the same trial but only during 1970 and 1971. In 1970 the yield of triticale lines was almost twice that of Apizaco (Table 3). However, in 1971, the yields of both crops were similar.

Under less productive conditions, triticale appeared to outyield barley, but before any strong conclusions can be drawn, the yield of triticales should be compared with locally adapted barley varieties.

In general, Mexican triticales were superior in height and lodging resistance and also had better fertility when compared with Californian lines. The Californian lines, however, were superior in winter-hardiness.

When the 1000 kernel weight of both the Mexican and Californian triticales was compared with 1000 kernel weight of Mexipak, they were almost the same. When the kernel size of the triticales was evaluated, shrivelling of the kernels was noticed.

TABLE 3. Comparison between some triticales and Apizaco in 1970 and 1971.

	1970		1971	
Variety	Yield (*t/ha*)	% compared with Apizaco	Yield (*t/ha*)	% compared with Apizaco
Apizaco	.84	100	4.70	100
Armadillo 133	1.59	189	4.29	91
Armadillo 135	1.62	193	4.11	87
Armadillo 1524	1.42	169	5.27	112

Triticale Research Program in Ethiopia[1]

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PINTO, F. 1974. Triticale research program in Ethiopia, p. 107–115. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Triticale has shown much promise in Ethiopia since its first trial in 1971, which was performed with the First International Triticale Screen Nursery material from CIMMYT. Subsequent trials at diverse locations provided a useful evaluation of varieties for disease, adaptation, and yield, and stimulated the interest of research workers.

Further success by triticale in 1972 in the wheat prenational trials encouraged hopes for triticale as a crop in Ethiopia. As well, tests of triticale as human food indicated that there were good prospects for utilizing triticale in the preparation of local foods.

A coordination program since 1973 is handling the distribution of triticale material to research workers throughout Ethiopia.

Résumé Les triticales se sont révélés très prometteurs en Ethiopie, depuis les premiers essais effectués en 1971 à partir du matériel provenant de la première pépinière internationale de sélection du triticale du CIMMYT. Les essais postérieurs effectués en différents endroits ont permis une évaluation utile des variétés sur le plan résistance aux maladies, facultés d'adaptation et rendement, en même temps qu'ils ont stimulé l'intérêt des chercheurs.

Les succès obtenus en 1972, dans les essais locaux de triticale par rapport au blé, ont renforcé les espoirs d'en faire une céréale cultivée en Ethiopie. En même temps, les essais d'emploi du triticale pour l'alimentation humaine se sont révélés prometteurs quant à son utilisation dans la préparation de mets indigènes.

Depuis 1973 la distribution du matériel (triticale) aux chercheurs de l'ensemble de l'Ethiopie s'effectue dans le cadre d'un programme de coordination.

THE first group of triticales was tried in Ethiopia in 1970, when the First International Triticale Screening Nursery (ITSN), received from CIMMYT, was grown at Holetta. The performance was so impressive that it was decided to retest the entries, together with any other material that could be obtained at fairly diverse locations the following year and some cultural trials were also started at Holetta. This series of observations provided a useful evaluation of varieties for diseases, adaptation, and yield. The general field performance at all test locations was again encouraging and considerable interest

[1]Delivered at the symposium by Hailu Gebremariam.

among research workers was immediately stimulated.

In 1972, the best of the screened varieties were included in the wheat prenational trials as well as fairly extensive observations in other parts of the country through the extension program. Their wide adaptation and surprisingly high yields, compared with the well-established wheats, left no doubts about the production potential of this new crop in Ethiopia.

Concurrently with the adaptation trials, small-scale tests were initiated to determine the suitability of triticale as human food. Initially, experienced housewives were employed to test traditional recipes and modify these as necessary. Although the tests were preliminary, and far from being refined, they did demonstrate that there was indeed a good prospect for utilizing triticale in the preparation of standard local foods.

The bulk of the material tested has come from the triticale program at CIMMYT. Only a few varieties of Canadian or USA origin have so far been tested. No crosses have yet been made locally but some 350 crosses in various generations were received from 1970 to 1972 and some selection was undertaken. A large number of selections made on the basis of nutritional quality is also being investigated. The ITSN's have been grown at Holetta and Debre Zeit each year. More recently, a large number of lines, in which the "well-filled kernels" trait is better expressed, was received and these lines are being studied.

Since the 1973 season, the coordination of the national triticale programs by the Holetta Research Station (IAR) has been formalized and 25 sets of national triticale trials or observations covering a total of 69 varieties were distributed to cooperating research workers for growing at 17 locations in the country. Three primary screening locations were developed at Awassa (1650 m, for stem and leaf rust screening), Holetta (2400 m for *Septoria*), and Sheno (2800 m, for stripe rust). These locations are already handling several hundred new lines this season.

The triticale research program has recently received a further stimulus through financial assistance from the International Development Research Centre (IDRC).

Variety Trials

The results of varieties in yield trials are presented in chronological order. The highlights of certain screening nurseries are also described.

1971 Season

BREAD WHEAT PRENATIONAL TRIAL

One variety, Triticale Mex. 68-69, was entered in the bread wheat prenational trial

TABLE 1. Bread wheat prenational trial "B," 1971. Yield, *kg/ha*.

Variety or line	Source	Alemaya	DZ(LS)	DZ(BS)	Holetta	Kulumsa	Awassa	Overall Avg	Overall Rank
Triticale (Mex. 68-69)	Holetta	1466	4575	2297	4195	5230	4483	3708	1
K4527 L45D1 (Mamba)[a]	Holetta	2302	3467	2323	3972	5105	3092	3377	2
Mean		2382	2667	1569	3502	3602	2369		
LSD 5%		–	578.5	593.2	553	649.6	–		
C.V. %		–	13.0	22.7	9.5	10.8	–		
Plant date		26/7	14/7	6/7	30/6	25/6	26/6		
Fertilizer ($N:P_2O_5$, *kg/ha*)		60:60	60:40	60:40	60:60	18:46	–		
Total rainfall, *mm*		380	672	672	786	363	–		
Source		Wheat Coordinator, Debre Zeit Experiment Station, Debre Zeit							

[a]The best of 16 bread wheats.

coordinated by Debre Zeit Experiment Station. The trial had 17 varieties.

The relevant yield data are given in Table 1. The yield of Mex. 68-69 averaged 3708 kg/ha over six rain-fed locations, which was 10% more than that of the best bread wheat, Mamba.

FIRST ITSN OBSERVATION SERIES

Fifty-two triticale varieties (47 from the first ITSN, 3 from Canada, and 2 from the USA) were also grown at seven locations in test-adaptation plots under rain-fed conditions in the highlands at altitudes ranging from 1650 to 2800 m. The wide adaptation of these triticales was clearly demonstrated and the mean yield of the best five varieties was over 3300 kg/ha. Leaf rust was high on most varieties (10–65 S), stem rust occurred on a few (0–40 S), and leaf blotch was generally low (10–80%), but leaf and ear infections of stripe rust were generally high (5MR–100S) except on the Canadian, and one USA, varieties. Based on this first national screening, five varieties were selected for entry into the national trials in 1972.

1972 Season

Two trials featured triticales in this season. Some of the ITSN's set new records for yield and these are mentioned.

WHEAT PRENATIONAL TRIAL "A"

Five varieties, three "Armadillos" and two "Badgers," were included in this trial, which was grown at five locations in the highlands ranging in altitude from 1650 to 2400 m. The trial was rain-fed and fertilized. Yield data are given in Table 2.

The five triticale varieties performed well at all locations and the best entry again outyielded the bread wheat check by 23% and the best of six durums in the trial by 26%, giving a mean yield of 4031 kg/ha.

Data on agronomic characters are presented in Table 3. The triticales were rather tall but did not lodge. They developed heavy leaf rust and gave test weights lower than those of the bread and durum wheats.

WHEAT PRENATIONAL TRIAL "B"

In a second trial of 13 late varieties, one triticale, Mex. 68-69, an Armadillo type, was included and grown at the same five locations as trial "A" (Tables 2 and 3). The triticale gave 3960 kg/ha, outyielding the best of 11 durums by 5% and the bread wheat check, Romany, by 31%.

TRITICALE OBSERVATION PLOTS

In addition to the trials, 41 varieties were screened at two locations for yield and susceptibility to disease. Eleven varieties were from the first ITSN, 18 from the second ITSN, 5 from California, and 7 from the high PER nutritional series of CIMMYT. Nineteen entries showed promise for the low to medium altitudes but only 13 had adequate stripe rust resistance at the higher altitudes. The three best entries were:

Variety	*Yield, kg/ha*
6TA-205-21 (USA)	5367
Kangaroo × MTE 20 PER, X384-106N-OM (CIMMYT)	3950
UM 940 "S" Kangaroo, X-1029-37M-1Y-1M-1Y-OM (CIMMYT)	3940

FOURTH ITSN "B" DRYLAND

This nursery was grown out-of-season by the Experiment Station at Debre Zeit but the light rains failed and supplementary irrigation had to be provided. Nineteen entries gave yields of over 6000 kg/ha, the best being 7780 kg/ha. Stem rust developed strongly on most of these lines and only 14 entries with low rust were retained. The more promising entries were:

Variety	*Yield, kg/ha*
Maya × Arm "S," X-2802-71N-2M-2N-OM	7180
Maya 11 × Arm "S," X-2802-37N-1M-4N-3M	6280
Inia 66	5800

FOURTH ITSN "A" IRRIGATED

This nursery was grown at Melka Werer (altitude 750 m) in the Awash Valley. No fertilizer was used as the land is relatively new and fertile. The crop was given nine irrigations at 7–12-day intervals as required, which provided a total of 110 cm of water. The plot size was very small, only 0.75 m^2, being a single 5-m row sown at 15 cm spacing. The best variety gave over 13,000

TABLE 2. Wheat prenational trials, 1972. Yield of triticales in relation to bread and durum wheat, *kg/ha.*

Rank Variety	Location: Alemaya	Awassa	Kulumsa	Debre B. Zeit soil	Holetta red soil	Overall mean
Prenational yield trial "A"						
1 Badger, F_2-68B-9B-ON	3411	3675	5418	4625	3028	4031
2 Badger, F_2-68B-5B-ON	3308	3658	4905	4122	3690	3937
3 Armadillo "S" X-308-6Y-2M-OY-19B-ON	3184	3775	4653	3987	3283	3776
4 Armadillo "S" X-308-6Y-2M-100Y-6B-ON	3177	3442	4322	3797	3338	3615
5 Armadillo "S" X-308-14Y-4M-102Y-301B-ON	3147	3267	4253	3647	3373	3537
6 Kanga	2695	1725	4510	3065	3587	3116
7 BYE²-TACE × Tc⁴ [(61-130-60-115) TME-Tc²/Z-BxW)]-D-27582-8M-6Y-5M-OY	3325	1217	4100	3545	2713	2980
6 Other durums in trial						
Location mean	3022	2248	4188	3327	3358	3171
LSD 5%	613	718	794	650	613	
C.V. %	12	21	11	16	10	
Planting date	21/7	4/7	5/7	29/6	1/7	
Rainfall, *mm*	312	405	454	635	625	
Prenational yield trial "B"						
1 Triticale (Mex. 68-69)	4817	3083	4752	3945	3205	3960
2 Cr "S" [(BYE²-TC² (Z-BxW)]/D-28984 20Y-6M-OY-LKDZ-OGDZ	6071	992	5112	2877	3812	3773
6 Romany	4803	1625	2197	2307	4180	3022
10 Other durums in trial						
Location mean	4727	915	3755	2345	3302	
LSD 5%	1022	661	660	766	532	
C.V. %	13	43	10	27	9	
Planting date	26/6	27/7	5/7	29/6	27/6	
Rainfall, *mm*	418	405	–	454	635	

kg/ha, and four others yielded over 9000 kg/ha.

Variety	*Yield, kg/ha*
(Inia-Rye)² × Arm, X-2145-2N-1M-4N-OM	13067
(Inia-Rye)² × Arm, X-2146-8N-1M-1N-OM	11733
[UM940(P4160-Tc1)] Arm "S," X-1974-1Y-1M-4N-OM	11733
Maya 11 × Arm "S," X-2802-58N-2M-7N-OM	9067
Siete Cerros (Bread)	5307

Cultural Practices

A rather extensive series of preliminary trials was conducted at Holetta from 1970 to 1972 to study the effect of sowing dates, seed rates, fertilization levels, and soil type on 12 crop varieties. One triticale, Mex. 68-69, was included in the study only from 1971. The variety takes about 66 days to head and 133 to mature at Holetta. Two soil types were used in the study: a red soil, which is an eutric nitosol, high in clay with a pH of around 6.0; and a dark grey soil, which is an eutric gleysol, fairly high in clay, and with a pH of 5.0–5.5 (Ochtman 1972). The latter is poorly drained and has been cambered into 8-m wide beds to improve drainage.

Effects of Sowing Date on Yield

On the basis of previous experience with wheat, four sowing dates spaced 10 days

TABLE 3. Wheat prenational trials, 1972. Agronomic and disease data.

Rank	Variety name	Days to head	Days to ripe	Ht (*cm*)	Lodging (%)	Shattering (%)	Diseases: Leaf blotch (0–9)	Powdery mildew (0–9)	Leaf rust C/I	Stem rust C/I	Stripe rust C/I	Test wt, *kg/hl*
Prenational yield trial "A"												
1	Badger, F_2-68B-9B-ON	54	125	107	0	3	2	4	19	3	0	72
2	Badger, F_2-68B-5B-ON	55	125	112	0	2	2	4	23	5	4	71
3	Armadillo "S"X-308-6Y-2M-OY-19B-ON	54	125	109	0	1	1	4	36	2	0	73
4	Armadillo "S"X-308-6Y-2M-100Y-6B-ON	54	124	109	0	1	3	4	40	1	0	72
5	Armadillo "S"X-308-14Y-4M-102Y-301B-ON	55	120	112	0	2	1	2	41	5	0	70
6	Kanga	52	115	91	23	1	3	2	1	0	0	81
7	(BYE^2-TACExTc^4) [(61-130-60-115) (TME-TC^2/Z-BxW)] D-27582-8M-6Y-5M-OY	64	122	79	0	0	2	2	28	17	0	82
Prenational yield trial "B"												
1	Triticale (Mex. 68-69)	54	122	110	0	5	1	1	27	4	0	79
2	Cr "S" [BYE^2-TC^2 (Z-BxW)] D-28984-20Y-6M-OY-LKDZ-OGDZ	70	118	85	0	0	1	1	9	17	8	81
6	Romany	68	115	117	10	1	1	1	1	39	0	80

apart in June and July were used. The crop was planted at seed rates of 150 and 125 kg/ha on the red and grey soils, respectively, and both soils received fertilizer at 60:60 N:P_2O_5 kg/ha. The yields obtained are shown in Table 4.

Where drained, the dark grey soil gave 20% more yield than the red. The triticale used, which is early maturing, proved suitable for both soils. It did best where sown in early July. Later sowings run the risk of frost in October–November. Rapid soil desiccation after the rains cease in September is another major constraint on the red soil.

TABLE 4. Effects of sowing date on the yield of triticale, Holetta 1971–72. Grain yields *kg/ha*, 12.5% moisture.

Sowing date:	15 June	25 June	5 July	15 July
	Red clay			
1971	4122	3308	3707	3056
1972	2535	2940	3701	3729
Mean	3329	3124	3704	3393
	Dark grey clay			
1971	2107	4055	3827	1906
1972	4941	4461	5190	4893
Mean	3524	4258	4509	3400

Seed Rates

Three seed rates — 100, 125, and 150 kg/ha — were tested in this study. The sowing date in 1971 was late June and in 1972 mid-June. A standard fertilizer at 60:60 (N:P_2O_5) kg/ha was used. The data obtained are given in Table 5.

Where the seed was broadcast, yield increased with higher seed rates in the tested range. In contrast, a high seed rate, though it showed on balance a similar trend, was less important for yield where the seed was drilled.

The optimum plant populations obtained were 275–300 plants/m^2 for both soil types, which suggests that losses were higher in the broadcast treatments. It is therefore recommended that 20% more seed be used in the latter case. Any variation in the sowing date, level of fertilization, resistance of the variety to lodging, seed weight, and germination could influence the recommendation and these are factors to be taken into account.

Fertilization Levels

The fertilizer requirements of triticale were studied in an investigation covering a number of crops. The design employed was a 42 factorial in a single replicate for each crop on each of the two soil types described earlier. Nitrogen and P_2O_5 were each used at 0, 30, 60, and 90 kg/ha. One triticale variety, Mex. 68-69, was grown in 1971 and 1972. These results have not yet been fully analyzed but the means of 2 year's data for each soil type (Table 6) suggest that the trends are similar for both soils, although higher yields were obtained on the dark soils. This work indicates that for both soils a rate of 60:60 ($N:P_2O_5$) kg/ha can be recommended and can be profitably increased up to the highest levels used, 90:90 ($N:P_2O_5$) kg/ha. No lodging occurred even at the highest levels tested.

Utilization Aspects

Milling Quality

Fifty-two samples derived from the adaptation trials at Holetta in 1971 were assessed at the Ethiopia Swedish Nutrition Institute.

TABLE 5. Effects of seed rates on triticale yields, Holetta 1971–72. Grain yields, *kg/ha*, 12.5% moisture.

Soil type: Sowing method:	Red clay — terraced Broadcast, ox-covered			Dark grey clay — 8-m beds Drilled		
Year:	1971	1972	Mean	1971	1972	Mean
Seed rates, *kg/ha*						
100	3560	3321	3441	2549	4146	3348
125	3775	3457	3611	2664	4412	3538
150	4154	3614	3884	2380	4706	3543

TABLE 6. Effects of NP fertilization on triticale yields, 1971–72. Grain yields, *kg/ha*, 12.5% moisture.

	P_2O_5 levels				Nitrogen
N levels	0	30	60	90	mean
			Red clay soil		
0	2334	1598	2018	1640	1873
30	1884	2290	2022	2182	2095
60	1996	2365	2825	2560	2437
90	2346	2884	3196	3484	2978
P_2O_5 mean	2115	2284	2515	2467	2345
			Dark grey clay soil		
0	2263	3022	2866	3472	2906
30	2868	2865	3126	2798	2914
60	2809	3331	3768	3832	3435
90	3183	3581	3756	3778	3575
P_2O_5 mean	2781	3200	339	3470	3208

A Fuchs horizontal disc mill with a mechanical sifter was used on grain conditioned to 12.5% moisture. No problem in milling was experienced and the bran separated cleanly from the endosperm. Flour extraction rates ranged from 54.0 to 72.0% for straight run flour, the wide range mainly reflecting the variability in grain filling. No flour moisture or ash contents were determined.

Protein Contents

Total protein contents were determined by the Analytical Section at Holetta on samples derived from the 1972 observation plots grown at that station. The values obtained ranged from 11.3 to 20.0% on a dry-matter basis. The relatively wide range makes this an important selection criterion, especially when selection against shrivelled kernels is done first.

Utilization as Food

The standard "bread" of Ethiopians is a form of leavened and baked pancake-type bread called "injera." This is made from whole meal using a variety of cereals or cereal mixtures. Injera made from teff, a unique cereal crop of Ethiopia, is the preferred staple food, especially of the middle and upper classes. In rural areas, injera may be made entirely from maize, sorghum, wheat, or barley or using mixtures of most of these grains with teff. Injera from teff keeps longer than that from barley, but that from other cereals becomes stale overnight. Several other local products are also prepared from cereals and used for breakfast foods or snacks. The most attractive injera is very white, light, thin, pliable, nonsticky, and noncracking, with a slightly sour taste and flavour that does not become stale for about 3 days. It should have a uniform distribution of small "pores" or "eyes."

Following initial efforts to demonstrate that it was possible to make several types of local foods from triticale, a technician was appointed to work out specific recipes and test them under standardized conditions. Various products were prepared in cooperation with the Ethiopia Swedish Nutrition Institute in Addis Ababa. Several triticale varieties in various blends with teff, maize, sorghum, barley, and wheat were used in making injera over a range of fermentation times. A special electrical hot plate was used to standardize cooking time. The evaluation of quality is done objectively and organoleptically by a panel of about five to eight people who, at present, only make an overall evaluation.

Whole meal triticale injera was not satisfactory, as it was mainly too sticky when cooked, and became stale too soon. Straight run triticale flour produced better colour but the other defects remained. Good injeras were obtained from 50% triticale and 50% teff and a similar blend with red sorghum was satisfactory. Comparable blends with barley made good injera, provided the barley was fermented slightly and the triticale not at all. The best triticale varieties tested were the Mex. 68-69 bulk and FasGro 204. Several Armadillos, Badger's, and one nutritional bulk proved less satisfactory.

Ganfo is a firm and slightly salted boiled meal that is served with spiced butter. The product from triticale compares favourably with that traditionally made from barley and, to a lesser extent, also from wheat.

Kitta is a form of "chapatti," in which the unleavened dough is baked on a hot pan for about 5 min on each side to produce a thick flat circular bread. The triticale product was very satisfactory compared with that normally made from wheat.

Dabo Kollo is a salty, toasted, snack-type product, normally made from wheat or barley. The triticale product was satisfactory.

Discussion

The triticale germ plasm now available in Ethiopia has a fairly wide base and a good potential for selection for good disease resistance, high yield, good grain type, and, if facilities become available, high nutritional quality. A good number of promising varieties has already been identified from the various screening and special nurseries and these are moving forward rapidly into trials at key locations in the country.

There is no doubt that the triticales can yield as well as or better than the bread wheats. In every trial conducted so far, the triticales have given top mean yields, exceeding the bread wheat and durums by 5–31% and in some of the screening nurseries by well over 100%. Mean yields of the present varieties in trials are running at about 4 tons/ha.

Of equal importance to high yield potential is the fact that the triticale yields are more stable and the varieties more widely adapted than wheats. Their performance at locations such as Awassa and Bako (1650 m), where maize is the predominant cereal and wheat is only marginal, is indicative of this point. The triticales also grow well at altitudes above 2600 m, where teff is not grown and where barley is the major, and often the only, crop grown. Their wide adaptation in Ethiopia and greater flexibility in time of sowing may contribute significantly to obtaining better yield stability compared with wheat.

The disease problems with the earlier varieties are not as serious as have been observed with wheat or barley. Most varieties have shown good resistance to the main diseases, namely stem rust and *Septoria tritici*, due probably to the very complex tetraploid parentage reinforcing the rye resistance in the earlier crosses. Resistance to leaf rust is not as good and resistance to the stripe rust races present in the highlands is now found in only a few CIMMYT varieties. In contrast, the varieties of Canadian or USA origin so far tested have shown excellent stripe rust resistance. Because of the interaction of disease with locality, it may be necessary to develop separate varieties for the higher altitudes in the near future. Efforts now in hand to screen new introductions, including early generation segregating material at local "hot spots" for the main diseases, should ensure that even more widely adapted varieties will be available in the future. It is hoped that an early check will be made of all new introductions to prevent the buildup of new diseases such as ergot and bacterial stripe.

The cultural trials conducted at Holetta since 1971, and at other locations more recently, have indicated similar trends to those with wheat. Early varieties of the Armadillo type would do better on the red soils for early July sowings. These soils dry out rapidly after the rains cease in September and later sowings suffer from moisture stress. On the heavier soils, better yields may be expected if drainage is adequate. The early July sowing is only possible using local planting methods as this soil is then too wet for mechanized planting. Although not tested, it is expected that a late variety planted in mid-June would be better for mechanized sowing, as has been shown for wheat. The recommended seed rates are similar to those for wheat, with 125 kg/ha being optimum for drilling and 150 kg/ha for broadcasting, both rates giving an optimum plant population of 275–300 plants/m^2. These are slightly higher than for barley and lower than now recommended for wheat. As new varieties are developed, their optimum plant populations will have to be verified. Fertilizer responses of triticales have been good and the trends are similar to those for wheat. It is possible that unfertilized triticale will also give better yields than unfertilized wheat.

There is little doubt that the triticales can be productive. The key to the successful commercial exploitation of the crop is clearly seen to lie in its utilization as human food. The current investigations, although still preliminary, have shown that good injera can be made using a 50:50 blend of triticale and teff. The economic benefits of such a blend are considerable when yields and prices are taken into account. Most other products produced from cereals can be prepared entirely from triticale. No investigations have yet been undertaken on the production of leavened bread. Nutritional studies have not yet been initiated, although some facilities for bioassays using mice have been offered by the Central Research Laboratories in Addis Ababa.

It is clear that the greater emphasis in the selection of a variety will have to be placed on quality. The milling value and protein content must be assessed in the early stages as considerable variation is seen to exist. The need for information on the protein composition, efficiency, and particularly the presence of harmful metabolites cannot be overemphasized. Only when the variety is completely safe for human consumption can utilization be confidently envisaged. Some variation between varieties in injera-making quality can be expected. The fact that the Mex. 68-69 bulk and FasGro 204 make good blends is fortunate as one is suitable for the medium to low altitudes and the other for the high altitudes. Most of the tests now being conducted are subjective and procedures are not very rigidly controlled. There is need for standardization, for more objective testing to be used, and for a much increased volume of testing as more material becomes available.

The emphasis on current utilization as human food is conditioned by the need of peasant farmers generally operating on a subsistence basis. Greater production and better nutrition would go a long way toward improving the rural standard of living. Especially in those areas marginal for wheat and teff or where, because production is low, local prices are high, triticales would be particularly useful. The fact that suitable blends of triticale with other cereals have been shown to make good injera improves the chances of accepting this cereal. Even in urban areas where teff is more commonly used, such blends would help cut the food bills quite substantially and result in an injera more nutritious than that made from teff alone. It is unlikely that teff production can keep pace with the demand. The introduction of triticales should ease the pressure on teff. This would require adequate publicity and extension especially on the utilization aspects.

It seems quite likely that, with the volume of research in the developed countries directed toward improving the protein content, composition, and efficiency, highly nutritious varieties, which are also highly productive, would soon be available. The relatively higher content of lysine in triticales compared to other cereals is well established and the high protein efficiency potential of triticale makes the crop a good choice for areas where human food requirements are so important.

Acknowledgments

The Agronomy Section at Holetta, which has handled the bulk of the work reported upon above, acknowledges the help of the Wheat Coordinator at Debre Zeit Experiment Station and of all the cooperators who carried out national trials or observations.

The program would not have advanced so satisfactorily without the help received from international organizations, notably CIMMYT, who have until now provided most of the material and much encouragement.

The assistance of the Ethiopia Swedish Nutrition Unit in conducting some of the utilization work is gratefully acknowledged.

Dr Dagnatchew Yirgou, General Manager, Institute of Agricultural Research, has played a large part in directing the triticale program. My thanks are also due to Dr N. R. Fadda, FAO Project Manager, IAR, for editing this paper.

Triticale Research Program in Algeria

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Abstract The CIMMYT outreach program began in Algeria in 1971 and had two main objectives: (1) to help identify problems and suggest solutions to the Algerian government; (2) to help establish a viable and effective cereals research program staffed by Algerians. Although triticale would probably rank low in priority with durum and bread wheats and alfalfa, the Algerian cereals project is willing to support a modest triticale research effort oriented solely toward production until more highly trained staff are available to assume a more ambitious program.

The limited experience with triticale in Algeria has indicated that triticale has excellent disease resistance particularly to *Septoria*; that although varieties suited to and selected under Mexican conditions are not particularly suited to Algerian conditions, the nurseries revealed the existence of very promising material in the F_2 bulks from Mexico; and that triticales promise to give more latitude in planting dates, which is greatly needed in Algeria.

Triticales might provide an option in the Algerian cropping program as partial replacements for barley and oats, and as forage crops and human food, depending on product acceptability.

Résumé Le programme de rayonnement du CIMMYT a démarré en 1971 en Algérie, avec deux objectifs principaux: (1) participer à l'identification des problèmes et suggérer des solutions au gouvernement algérien; (2) participer à la mise en oeuvre d'un programme viable et efficace de recherches céréalières conduites par des Algériens. Bien que sur le plan des priorités, le triticale se classe sans doute dans ce pays bien après le blé dur, le blé tendre et la luzerne, le programme céréalier de l'Algérie comporte une modeste initiative de recherche sur le triticale et ce, uniquement sur le plan de la production jusqu'à ce que l'on ait pu former un personnel plus compétent, lequel pourra alors mener à bien un programme plus ambitieux.

Selon l'expérience limitée que l'on a du triticale en Algérie, cette céréale a une excellente résistance aux maladies, en particulier à *Septoria*; bien que les variétés sélectionnées en fonction des conditions existant au Mexique et qui leur sont adaptées ne soient pas particulièrement à celles de l'Algérie, les essais en pépinière ont révélé l'existence d'un matériau très prometteur dans les ensembles de F_2 d'origine mexicaine; en outre, les triticales semblent devoir fournir une gamme de dates de semis plus étendue, ce qui répond en Algérie à des nécessités de tout premier ordre.

Les triticales peuvent fournir une option intéressante pour les programmes céréaliers en Algérie, à titre de remplaçants partiels de l'orge et de l'avoine, à titre de culture fourragère, voire pour l'alimentation humaine suivant la manière selon laquelle le produit sera accepté.

ALGERIA has been independent for just over 10 years. But one should not think of it as an underdeveloped country in the traditional sense. The French colonizers had developed much of the agricultural land of Algeria during their 130 years of occupation. They planted vineyards, olive groves, citrus orchards, cleaned much of the land of rocks and laid out fields for cereal culture in a manner that is highly suited to modern production methods.

During the final years of the French presence in Algeria, the country exported wheat, mostly to Europe, and supplied France with much of the high quality durums used in the pasta industry. Over 300,000 tons were exported in the last important exporting year before the French departed.

When they left, management left with them. Algeria soon became a grain-deficit country, importing recently as much as 300,000–400,000 tons annually.

The 1972 harvest was particularly good and domestic supply and demand was nearly equal. However, dry weather, combined with severe grassy-weed infestations in late spring, greatly reduced yields in 1973, with the result that Algeria may have to import up to 500,000 tons of wheat to meet its needs before the 1974 crop is harvested.

Algeria's population is about 15,000,000 and various estimates suggest that population growth is about 3% annually. This means 450,000 extra people have to be fed every year.

The main cereal products consumed are couscous, made mainly from durum wheat, and bread, both of which are consumed in large quantities.

Because of the absence of management previously mentioned, the weed problem is building up in the country's wheat fields. Sheep are permitted to graze wherever a crop is not actively growing, including land that is theoretically in clean fallow. However, they do not eat all the weeds and thus the field is well sown with weed seeds for the following year when it will be in wheat. This results in severe infestations of weeds and since the grassy ones, like ryegrass and wild oats, cannot be controlled by 2,4-D, they take over, resulting in what Dr F. J. Zillinsky of CIMMYT describes as the production of "short-headed varieties."

The CIMMYT outreach program in Algeria began in 1971 with a wheat breeder and three production agronomists. The program has two main objectives: (*a*) to help identify problems and suggest solutions to the Algerian government; (*b*) to help establish a viable and effective cereals research program staffed by Algerians.

The Algerian government has given main priority to the production of durum and bread wheats. It is also greatly interested in the development of *Medicago* (annual alfalfa) as an alternative to fallow. Successful introduction of Medics into Algeria might relieve grazing pressure on fallow land, decrease the need for nitrogen fertilizers, improve soil tilth, reduce erosion, and aid in weed control.

Triticale would probably rank fourth in priority. However, the Algerian cereals project is willing to support a modest triticale research effort, oriented solely toward production, while awaiting the return of Mr Benbelkacem, now in training at CIMMYT, to assume direction of a more ambitious program.

The existing triticale program in Algeria is oriented solely toward production. Last year we included Cinnamon and three advanced lines in several yield trials throughout Algeria. In an irrigated trial near the Morroccan border, Cinnamon ranked 16th in a trial including 20 bread and durum varieties with a yield of 37.8 Qx/ha. In the same trial, Inia was the top yielder with 50 Qx/ha. This was the highest yield obtained with any triticale in any of our trials.

In another trial (rain-fed), Cinnamon was 10th of 20 varieties with a yield of 26.4 Qx/ha and Mexi 1601 (Utique) was a high yielder with 34.4 Qx/ha.

At Sfisef, the three advanced triticale lines were last in a trial of 20 bread and durum varieties.

Two nurseries were established: one near Oran at 90 m elevation in a 400-mm rainfall zone, and a second near Sfisef at 600 m elevation with 430 mm rainfall.

We space-planted about 20 kg of F_2 bulk sent by Dr Zillinsky. We observed wide variability in this population and were able to select 3000–4000 plants with high fertility and promising agronomic characteristics. These will be planted in head rows this autumn at both sites and from these rows we hope to select perhaps 100 promising lines for replanting in 1974.

What have we learned from this limited experience with triticales?

(*a*) Varieties suited to and selected under Mexican conditions are not particularly suited to Algerian conditions; (*b*) triticales have excellent disease resistance, particularly to *Septoria* — this is very significant because in 4 of the 5 years I have worked in North Africa, *Septoria* has been a serious problem in wheat production; (*c*) the nurseries revealed the existence of very promising material in the F_2 bulks from Mexico — perhaps our experience will be the same as California's, where similar results were obtained; (*d*) triticales promise to give us more latitude in planting dates, which is greatly needed in Algeria.

Possible Uses of Triticale in Algeria

Triticales might provide an additional option in the Algerian cropping program. They could be used: (*a*) to partially replace barley — the area planted to barley is roughly the same as that planted to bread wheat; (*b*) to replace oats in the vetch–oat crop now used for hay; (*c*) as a forage crop; (*d*) as a human food, depending, of course, on product acceptability.

Triticale Program and Potential in Kenya

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Abstract Work on triticale has been going on at the Plant Breeding Station at Njoro, Kenya, since 1967, when material from the University of Manitoba was received. Later, in 1970, CIMMYT also forwarded triticale material. Triticale lines chosen for disease-resistance trials have fared better than wheat checks, and have done very well under dry conditions.

The breeding program aims to develop varieties of triticale with wide adaptability and resistance to stem, stripe, and leaf rusts, through a cooperative program with CIMMYT and the University of Manitoba.

The objectives of the agronomy program are to determine the optimum levels of nitrogen and phosphate fertilizers, to determine the optimum seeding rates and row spacings, and to evaluate the weed problems and other cultural methods and practices.

Triticale is also being considered as a livestock and poultry feed. Feedlot industries requiring grains have been started up in Kenya, and as well egg and broiler production and processing factories are developing that will be able to use triticale.

Résumé Les travaux sur le triticale ont commencé en 1967 à la station de phyto-sélection de Njoro, au Kenya, à la suite de l'envoi de sélections de triticale de la part de l'Université du Manitoba. En 1970, c'est le CIMMYT qui fait parvenir à Njoro des plants de triticale. Les lignées retenues pour les essais de résistance aux maladies se sont mieux comportées que les blés témoins et se sont fort bien comportées dans des conditions sèches.

Le programme de sélection a pour but de créer des variétés de triticale qui puissent largement s'adapter et résister à la rouille de la tige, à la rouille striée et à la rouille des feuilles, et cela en collaboration avec le CIMMYT et l'Université du Manitoba.

Les objectifs du programme agronomique sont de déterminer les doses optimales d'engrais azoté et phosphaté, le nombre de semis et l'espacement des rangs maxima, ainsi que de faire le point sur les problèmes d'adventices et les diverses méthodes et procédés de culture.

On se préoccupe également de la place du triticale en tant qu'aliment du bétail et des volailles. L'engraissement en parcs au moyen de grains vient de démarrer au Kenya, ainsi que la production industrielle des oeufs et des poulets en même temps que s'installent des établissements de transformation qui pourront utiliser le triticale.

STEM rust of wheat is probably more severe in Kenya than in any other area of the world. Triticale is also attacked by this same stem rust. Since the highly virulent races of stem rust prevalent in East Africa are distinctly different from races prevalent in other parts of the world, selection and breeding for rust-resistant triticale cultivars for Eastern Africa must be carried out in Eastern Africa. The Plant Breeding Station at Njoro, Kenya, has a climate ideally suited to screening for resistance to stem rust with a medium altitude (2300 m) above sea level. At higher altitudes (3000 m) at Molo and other areas, screening for stripe rust is possible. Because altitudes where wheat is grown vary from 1800 to 3000 m and the soil types and amount of rainfall vary, the Njoro area is ideal for agronomic trials and selection of lines of wide adaptability.

Triticale work at Njoro started in a small way in 1967 when Dr L. E. Evans introduced triticale material from the University of Manitoba, Winnipeg, Man., Canada. These were screened for disease resistance and selections were made for stem, stripe, and leaf rust resistance. The second major source of material was the first International Triticale Screening Nursery grown in 1970. In that year 21 out of 46 strains were retained for further screening in 1971. By 1971 there was enough screened material for a trial at two sites. Thus the Plant Breeding Station at Njoro conducted the first Kenya Triticale Variety Trial in 1971, which consisted of five triticale lines and two wheat checks. In 1972, the station conducted the second Kenya Triticale Variety Trial consisting of 14 triticale lines and two wheat checks. Results of the two trials at Njoro and Molo so far are very encouraging, particularly concerning yield and disease resistance. In these trials the best triticale lines gave higher yields than the best wheat lines in adjacent trials. The severely rusted wheat checks gave very low yields. The early part of the 1973 main season was very dry. The wheat crop at the station generally appeared to suffer extensively; the triticale crop planted at the same time was doing very well under these dry conditions. We had only 169 mm of rain at Njoro for the period mid-April–July.

Breeding Program

The objective of the breeding program is to develop varieties of triticale with wide adaptability and resistance to stem, stripe, and leaf rusts. This objective can be achieved most rapidly through a cooperative program with the existing triticale projects at CIMMYT, Mexico, and University of Manitoba in Canada. F_2 and F_3 material obtained from the existing projects will be screened at sites in Kenya that are at high, medium, and low altitudes for stem, stripe, and leaf rust resistance. Field screening for rust resistance would be accompanied by a program of testing seedling reactions of promising lines to individual races and a program of race identification. Superior lines with plump seed types will be yield-tested at various locations to select for wide adaptability, and promising lines will also be returned to the existing projects for quality testing and use in crosses. Crosses will be made to incorporate rust resistance into triticale using Kenya rust-resistant bread wheat lines and varieties. Crossing among triticale lines with different objectives will also be done at this station.

Agronomy Program

The objectives of this program will be to determine the optimum levels of nitrogen and phosphate fertilizers, to determine the optimum seeding rates and row spacings, and to evaluate the weed problems and other cultural methods and practices.

The current triticale program in Kenya includes the following materials:

(1) Triticale Variety Trial (TVT/73): consists of 16 introduced triticale strains and four wheat checks grown at three sites: low (1900 m), medium (2100 m), and high (2800 m) altitudes. The 16 triticale strains included in this test were reselected from either TVT/72 or Triticale Preliminary Trials 1972.

(2) Preliminary Trial J/73: included are 21 triticale lines and four wheat checks grown only at Njoro. The 21 triticale lines were selected from triticale nurseries last year.

Other nurseries consisted of: (1) 68 F_3 triticale lines of plump seed and resistant to stem, stripe, and leaf rusts, selected from F_2 bulk at Njoro and Molo in 1972; (2) 517 F_3 triticale lines resistant to the three rusts but with less plump seed, selected from the same F_2 bulk; (3) 270 F_2–F_8 plots, selections from Toluca, Mexico, in 1972; (4) 33 F_2 plots sent by the CIMMYT triticale program; (5) five large plots of CIMMYT triticale increases for quality testing at CIMMYT; (6) 64 TCL plots, observation lines from previous introductions; (7) 4-ha space plants of F_2 TCL bulk from the University of Manitoba and CIMMYT.

Food crops have been the most important source of protein and they will certainly continue to have this function in the future. To date in many parts of the developing countries 80% of the entire direct consumption of protein originates from plants. Cereals play a key role in the supply of vegetable protein. In developing countries such as ours, maize, sorghum, millet, rice, and wheat contribute more than half of the protein supply in direct human consumption. These cereals are generally considered to be of reduced nutritional quality in comparison to other protein sources. This is due to their low protein content, and low levels of the amino acids, lysine and tryptophan.

Qualitative improvement in nutrition by better provision of vegetable food in areas where the population lives partly or fully on subsistence can be achieved by the cultivation of plants rich in protein and vitamins. Many triticale lines have higher protein potential than most cereals grown under the same environmental conditions. Furthermore, triticale protein contains more lysine.

As the income of individuals in Kenya has been increasing, so has the consumption of leavened bread. Triticale could be used in the production of bread, but generally the tetraploid wheats ($2n = 28$) are being used as the wheat parents for triticale rather than the hexaploid type ($2n = 42$), and tetraploid wheats lack the D genome, which is the location of most genes for elasticity in the gluten, an essential bread-baking quality character. This is, therefore, lacking in hexaploid triticale (Larter 1968). The type of normal leavened loaf of bread usually made from bread wheat flour is unlikely to be baked from hexaploid triticale flour. However, triticale flour can be blended with wheat flour of high baking quality to produce an acceptable loaf of bread.

Considering the eating habits of Africans — West Africans, East Africans, and Kenyans in particular — bread in the form of a loaf is used by fewer people. Hunger in Kenya is felt not when there is a wheat crop failure but a maize crop failure.

Ugali is the main food in Kenya and is made of maize meal. When there was a surplus of wheat in Kenya in 1968–70, there was a shortage of maize resulting from excessive maize export. Wheat flour was used in enriched maize meal consisting of 80% granulated maize meal and 20% wheat flour. However, this product was generally unacceptable to the consumers since wheat flour gluten is elastic, making it more difficult to cook ugali. Hexaploid triticale flour, which has nonelastic gluten, would be acceptable to the consumer if used in enriched maize meal. Therefore, triticale can fit directly into the diet of the largest number of the population more easily than bread wheat.

Livestock and Poultry Feed

Triticale appears to be an excellent livestock and poultry feed. Data from triticale research in other countries indicate that feeding efficiency of triticale is equal or superior to that of wheat, barley, and grain sorghum in high-energy finish rations for cattle and pigs. With the introduction of feedlot feeding initiated by the Beef Research Station at Lanet Nakuru in 1971, wheat, barley, maize, and other small grains will be in demand for livestock feed in Kenya, and other East African countries will follow Kenya's example. Many farmers who hitherto had to feed their livestock on grassland are changing and starting feedlot industries in Kenya. Five large farmers had finished constructing their feedlots by the end of 1972 in Rift Valley Province alone. Each of them was to put through approximately 5000 head of cattle per year. And there are 7 million head of beef cattle in the country. The first mobile feed mill was stationed at Nakuru in August 1972 and by the end of the year, 273 tons of feed were processed from roughages, grain, and molasses–urea mixture. The great demand for the mill indicates an expanding feedlot industry where triticale and other cereal grains will fit in.

The "back yard" poultry-rearing system still practiced by poultry farmers in Kenya is now proving uneconomical, since the markets are situated in large urban centres. Egg and broiler production and processing factories are being formed (e.g., BAT). These will certainly need large quantities of layers of mash, chick and broiler mash, or feed. Triticale grain will certainly be used in these industries.

The high yield potential of triticale has already been demonstrated in East Africa. It is expected that with further breeding, varieties with wide adaptability and resistance to stem, stripe, and leaf rusts will result in making triticale a new commercial food for humans and for livestock and poultry feed in East Africa.

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Triticale Breeding Experiments in Chile[1]

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PARODI, PATRICIO C. 1974. Triticale breeding experiments in Chile, p. 125–128. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC-024e.

Abstract Triticales are new in Chile. The first seeds, from CIMMYT's Fourth International Triticale Screening Nursery (irrigated), were planted in 1972 at the Pirque Experiment Station of the Catholic University of Chile. Results were limited but promising. The best triticales yielded about 80% of the wheat controls, but some lines showed excellent agronomic types; many were resistant to the prevalent races of *Puccinia striiformis*, *P. recondita*, and *P. graminis*. Their main advantage, however, proved to be the high protein content, which ranged from 9.2 to 18.5%.

A much larger and more complete set of triticale germ plasm was received from CIMMYT in 1973, and was planted under irrigated and dry-land conditions. This year's results may provide a sounder basis to determine the scope of the breeding program.

Résumé Le triticale est un nouveau venu au Chili. Les premières semences y furent mises en terre en 1972 à la Station Expérimentale de Pirque de l'Université Catholique du Chili; elles provenaient de la quatrième pépinière internationale de sélection du triticale (à l'irrigation) du CIMMYT. Les rèsultats obtenus furent limités mais prometteurs. Le rendement des meilleurs triticales atteignit environ 80% de celui des blés témoins, mais certaines lignées se révélèrent excellentes sur le plan agronomique; un grand nombre d'entre elles étaient résistantes aux *Puccinia* sévissant au Chili: *P. striiformis*, *P. recondita* et *P. graminis*. Leur principal avantage s'est cependant révélé être leur teneur élevée en protéines qui allait de 9.2 à 18.5%.

Un lot plus important et plus complet de matériel génétique est arrivé du CIMMYT en 1973, et ces triticales ont été semés en culture sèche et en culture irriguée. Les résultats de cette année pourront fournir une base plus solide de détermination de la portée du programme de sélection.

CEREALS have a significant importance in Chile's economy. Wheat represents 15% of the total agricultural production, and in 1970 was, along with beef cattle, the main component of the agricultural sector (ODEPA 1970).

The area planted with wheat up to 1970 was consistently over 700,000 ha, or approxi-

[1]This paper was prepared before the 11 September 1973 events in Chile. Some of its forecasts may be thus invalid. Nevertheless, the need for triticale development remains as urgent as indicated.

mately 55% of the land used for annual crops (Table 1). Wheat production decreased in 1971 and 1972, and the situation will not likely change in 1973. The reasons for this decrease are a combination of political, social, and economic factors that fall outside the scope of this paper.

The average daily diet of the Chilean population is 2720 calories (FAO 1970); of these, 1430 calories, or approximately 52%, are supplied by cereals, mainly wheat. Wheat contributes about 40% of the energy and 50% of the protein in the national diet, and is thus its most important constituent.

Wheat commercial cultivars have a comparatively low protein content (Table 2) and although the trend in recently produced cultivars is toward higher protein levels, the average remains inadequately low. This emphasizes the need to produce grains with a genetically higher protein content, so that the diet may be enriched with more and better protein, at no additional cost to the consumer.

In spite of the importance of wheat in the country's economy and in the dietary requirements of the population, Chile imports a considerable amount of this cereal (Table 3). Import estimates for 1973 range from 1,000,000 to 1,507,000 tons, or from 47 to 71% of the total needs. The outlook for the next few years is not too promising. In addition, the high price of wheat, coupled with the country's unfavourable balance of payments, dramatizes the requirement to locally produce more grains to feed the population.

Because wheat is mostly used for human consumption, and production does not meet demand, other grains have to be grown for animal feed. Corn is undoubtedly the most important animal feed in Chile. The north-central region, located approximately between 28°30′ and 36°30′ lat S, possesses optimum environmental conditions for corn production. Yields have increased significantly since 1961 (Table 4) but the reduced area planted with corn has maintained an inadequate level of production, the deficit becoming acute after 1965, when the poultry and swine industries were expanded. After 1970, the variables affecting corn production were altered, as in wheat, and despite recent efforts, major

TABLE 1. Area, production, and yield of wheat in Chile, 1948–72.

Year	Area (*'000 ha*)	Production (*'000 tons*)	Yield (*100 kg/ha*)
1948–52	777	928	11.9
1953–56	772	989	12.8
1964	852	1320	15.5
1965	849	1276	15.0
1966	784	1167	14.3
1967	719	1204	16.7
1968	700	1220	17.4
1969	740	1307	17.7
1970	776	1343	17.3
1971	724	1145	15.8
1972	540	810	15.0

TABLE 2. Protein percent of spring wheat cultivars released for the north-central region of Chile.[a]

Cultivar	% protein	Year released
Menflo	10.4	1954
Vilufén	10.0	1956
Orofén	10.8	1959
Rulofén	11.6	1960
Huelquén	10.7	1963
Platifén	14.1	1964
Centrifén	11.5	1965
Collafén	11.4	1967
Yafén	12.6	1967
Toquifén	12.6	1969
Mexifén	11.3	1970

[a]Source: INIA, Chile.

TABLE 3. Chile's wheat imports, amount and cost, 1970–72.[a]

	Year		
	1970	1971	1972
Amount (*tons*)	200,371	502,200	740,000
Cost (*US$*)	13,357,000	36,600,000	55,000,000

[a]Source: ODEPA (1970).

changes in the present trend may not be expected. The import situation for corn is shown in Table 5. Current estimates for the 1973–74 season range from 450,000 to 608,000 tons, or from 55 to 72% of the total needs.

The conditions of the 1971–73 period should be considered "abnormal" for wheat and corn production, as for agriculture in general. But even under "normal" conditions, Chile needs to produce more grain, and grain with better nutritional quality, since replacement with other sources of protein seems to be difficult and expensive.

The alternatives are not simple. It had been planned to concentrate on export commodities such as fruits, the returns for which might pay for wheat and corn imports. The instability of the world grain market makes this possibility rather dangerous. Sorghum has been tested on a limited basis, but it has to compete for land with corn, and as indicated, corn yields are difficult to surpass. Sorghum, however, does not represent a viable solution to supply grain for direct human needs. Research with soybeans was initiated a few years ago. Low yields are still a major problem, but we are certain that our scientists may overcome them. Still, there are years of work ahead before satisfactory results may be obtained, and even then, although soybean-enriched flour may be used for bread-making, the demand for bulk will still remain unsatisfied.

TABLE 4. Area, production, and yield of corn in Chile, 1960–72.

Year	Area *(000 ha)*	Production *(100 ton)*	Yield *(100 kg/ha)*
1960/61	83.3	162.8	19.5
1961/62	84.6	180.8	21.4
1962/63	84.4	176.0	20.9
1963/64	88.2	241.0	27.4
1964/65	87.6	259.9	29.7
1965/66	80.7	285.3	35.4
1966/67	92.2	362.2	39.3
1967/68	88.5	320.8	36.2
1968/69	58.4	153.8	26.3
1969/70	73.9	239.1	32.4
1970/71	77.0	258.3	33.5
1971/72	84.5	180.2	21.3

TABLE 5. Chile's corn imports, amount and cost, 1970–72.[a]

	Year		
	1970	1971	1972
Amount *(tons)*	163,579	270,300	465,000
Cost *(US$)*	10,826,000	20,600,000	31,620,000

[a]Source: ODEPA (1970).

Triticales are now in Chile. The first seeds, from CIMMYT's Fourth International Triticale Screening Nursery (irrigated), were planted in 1972 at the Pirque Experiment Station of the Catholic University of Chile. Results are limited but promising. The best triticales yielded about 80% of the wheat controls, but some lines showed excellent agronomic types; many were resistant to the prevalent races of *Puccinia striiformis*, *P. recondita*, and *P. graminis*. Their main advantage, however, proved to be the high protein content, which ranged from 9.2 to 18.5%.

A much larger and more complete set of triticale germ plasm was received from CIMMYT in 1973, and was planted under irrigated and dry-land conditions. This year's results may provide a sounder basis to determine the scope of the breeding program.

When initiating a triticale breeding program, several aspects must be considered. No matter how good the potential cultivars may be, if conditions conducive to high and efficient agricultural production are not restored, the cultivars will be of no use. If such conditions are restored, as we hope they will be during the second half of this decade, now is the best time possible to initiate such a breeding program, so as to be prepared with suitable cultivars when proper conditions are available.

A triticale breeding program in Chile should have the following goals:

(1) *Develop high-yielding spring triticale cultivars that will supplement grain production for human consumption.* Such cultivars

would be planted in the wheat-growing areas. Chances that new land may be opened for triticales, or diverted from other crops to triticales, are limited. Triticales would then compete with wheat for the same land; whether this is irrigated or dry land remains to be seen. Most of the area in the region, however, is irrigated, and the best soils and best yields are usually found under irrigation. Triticale cultivars must show yield advantages over wheat cultivars, or at least perform comparably under similar environmental conditions.

(2) *Develop triticale cultivars with adequate milling and baking characteristics.* If triticales are to compete with wheat for land, their flour must have the appropriate milling and baking quality, so that they may be used directly for bread-making, or in mixtures with wheat flour without lowering the quality level. Only in a secondary manner should triticales be considered as a source of cookie flour.

(3) *Develop triticale cultivars with high protein quality and quantity.* To compete with wheat, triticales must show advantages other than yield, since yield levels attained with one set of cultivars may be soon surpassed with the next set developed by the breeding programs. The importance of wheat as a source of food has been indicated. To emphasize it, it should be noted that the average Chilean incorporates in his diet 77.8 g of protein per day, of which 39.3 g are supplied by cereals, mainly wheat. Wheat consumption is obviously high, but its contribution to the diet, both as protein and as total calories, is inadequate. The chances that the proportion may be altered and replaced by animal protein are limited. Triticales may produce more protein per unit area even with lower yields, but if by using high-protein triticale flour, more nutritious bread and other flour derivatives may be supplied to the population, triticales would justify the effort and money invested in a breeding program.

(4) *Develop triticale cultivars for animal feed.* Triticales, or any other small grain, may at present compete for yield with corn in Chile's north-central region. High-yielding triticale cultivars, with poor milling and baking quality may be grown, however, in areas where topography or summer moisture, or both, preclude corn production. In addition, early maturing triticales could be introduced into a double-cropping system, followed by corn or other crop, increasing the output per unit area of land.

With these considerations in mind we have taken the first steps to initiate a triticale breeding program, based on CIMMYT's germ plasm. The magnitude of the program will depend on the funds available to finance it.

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Expanding the CIMMYT Outreach Programs

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Abstract The first outreach of CIMMYT's predecessor organization was accomplished through sending out genetic material developed within Mexico. A more formal relationship was entered into through the development of the Inter-American Yield Nursery, first distributed in 1959, which later developed into the International Spring Wheat Yield Nursery, first grown in 1964–65. As well, a training program was established at CIMMYT for scientists that operated from 1960 to 1973.

CIMMYT was officially formed in 1966 and since then new nurseries have developed and more trainees have studied at CIMMYT.

When a country indicates that food production is a priority item, CIMMYT at the government's request, can assist in securing funds from agencies to meet part of the financial burden. Once this is found, CIMMYT personnel may assist in the organization of the research base and the ensuing production programs. CIMMYT can provide training for young scientists and assist in furthering the education of those who should be further trained. CIMMYT personnel can provide advice and also genetic materials or facilitate exchange with scientists in other countries. Regional activities are eventually set up that better serve the region and also tie together the various national programs.

The triticale outreach program has grown from the distribution of 30 nurseries in 1969 to 208 nurseries in 1973. Triticale was readily accepted because the CIMMYT bread wheat program had already established connections with the countries receiving triticale. Three scientists were trained within the triticale program at the request of their government in 1973. It is suggested that each country that is interested in this crop should grow the nurseries, become familiar with the crop, stay abreast of the improvements being made, and at that point, when they are confident that this is a crop suitable for their production, give it full status as a new cereal crop.

Résumé La première réalisation importante de l'organisme ayant précédé le CIMMYT a été d'expédier à l'extérieur du matériel génétique mis au point au Mexique. La création de la pépinière de multiplication inter-américaine a permis à partir de 1959 l'établissement de relations plus officielles, cet organisme étant devenu la pépinière internationale de multiplication des blés de printemps à partir de 1964–65. En même temps, de 1960 à 1973, a eu lieu au CIMMYT un programme de formation de spécialistes.

La création officielle du CIMMYT date de 1966, qui a accueilli depuis lors davantage de stagiaires en même temps que l'on créait de nouvelles pépinières.

Lorsqu'un pays fait savoir que la production alimentaire constitue pour lui une priorité, à la demande du gouvernement le CIMMYT peut lui apporter son aide sous forme de fonds provenant de différents organismes, prenant ainsi en charge une partie du fardeau financier. Le CIMMYT peut ensuite également intervenir en fournissant du personnel qui aidera à organiser la base de recherches et les programmes de production qui en découlent. Le CIMMYT peut fournir une formation aux jeunes chercheurs et apporter son aide au parachèvement des études de ceux qui en ont besoin. Le personnel du CIMMYT peut donner des conseils et fournir du matériel génétique, ou faciliter les échanges avec les spécialistes d'autres pays. Les activités régionales sont mises en place afin de mieux desservir toute une zone géographique et unir les différents programmes nationaux.

Le programme de diffusion du triticale a pris beaucoup d'expansion, passant de 30 pépinières en 1969 à 208 en 1973. Cette céréale a été rapidement acceptée du fait que le programme du CIMMYT d'utilisation du blé pour la panification avait déjà établi des liens avec les pays recevant du triticale. En 1973, à la demande de leurs gouvernements respectifs, le CIMMYT a formé trois spécialistes dans le cadre du programme triticale. On estime que chaque pays intéressé par cette culture devrait mettre en place des pépinières, se familiariser avec cette céréale, se tenir au courant des améliorations puis, une fois assuré que le tritricale est une culture qui convient à la production locale, lui donner officiellement le statut de nouvelle culture céréalière.

OUTREACH has become a very broad and complex subject. When CIMMYT first began its outreach programs, many of the problems were rather clear-cut and definable. The basic problem was: Country X produces too little food for its people. What is CIMMYT able to do to help fill this need? The first outreach of CIMMYT's predecessor organization was accomplished through sending out genetic materials developed within Mexico. These were first sent to Latin American countries. There was also a certain outreach through the appointment of scientists such as Dr J. Rupert to Chile. He had developed his experience in Mexico. A more formal relationship was entered into through the development of the Inter-American Yield Nursery, which was first distributed in 1959. About this time, Dr Borlaug was requested to accompany Drs Harrington and Vallega of FAO to assess the needs of many countries of the Near and Middle East.

As a result of the recommendations arising out of this survey, a training program was initiated in Mexico for young scientists of this region. Although some less formal training had been done in Latin America prior to that time, in this new arrangement, trainees were selected from the region by the FAO coordinator, funds in support of the program were supplied by the Rockefeller Foundation, and Dr Bolaug and his group at CIMMYT did the training. This program operated from 1960 to 1973 and many scientists received training under its provisions.

With the advent of this first group of trainees and at their request, the Inter-American Yield Nursery was expanded and became the Near East-American Yield Nursery. Sets were increased and sent throughout the countries of the Middle East beginning in 1963. This, in turn, developed into the International Spring Wheat Yield Nursery, which was first grown in 1964–65.

Meanwhile, CIMMYT was formed officially in 1966, and since that time considerable growth has occurred. Within the wheat section, durum, triticale, and barley research were successively undertaken. New nurseries were developed, and these were duplicated in each crop. More and more trainees came. CIMMYT became directly involved in certain countries' programs with the appointment to them of CIMMYT's personnel. In all cases funding for these programs has been provided by one or another outside agency insofar as the wheat program is concerned.

The arrangements regarding personnel may take the form of a complete CIMMYT team, or a team that consists partly of CIMMYT personnel and partly of employees of other agencies.

There are now about 40 trainees per year, several visiting scientists for varying periods, and visitors now numbering in the several thousands yearly. From the few nurseries circulated in 1960 there are now, in 1973, 1083. As late as 1971 there were 420. CIMMYT core staff have similarly increased their travel committments to different countries to advise and be advised on problems of those programs. Recently, CIMMYT has officially entered the field of regional activities through the appointment of Dr Gene Saari to the CIMMYT staff as regional pathologist, covering Asian and African national programs. At the same time, regional nurseries comprising varieties of the four crops have been instituted in both the eastern and western hemispheres to monitor disease and insect problems. Thus CIMMYT's outreach program has gradually increased in its complexity.

Regarding national programs, a start was normally made by using improved varieties and genetic materials, but this was only a start. The research organization had to be built or modified. Extension had to be joined to research. Production practices for higher yields demanded greater fertilizer supplies and governments had to react. Incentive prices were set and maintained to encourage production. The resulting increased yields strained traditional storage capacity to the breaking point. Transport was put under extreme pressure, marketing had to be developed, and second generation socio-economic problems arose.

Thus, a program that initially involved only the genetic improvement of material, rapidly developed into a very complex system of interrelated problems.

Philosophy of Outreach

I am not a believer in using the hard sell to persuade governments to accept CIMMYT services. If the government does not give high priority to agricultural research and production, it is unlikely to devote time, energy, or resources to assist its own program. There must be a desire for assistance before there can be mutual respect. Where this is lacking, any funding put into the program will pay little in the way of dividends. This will not result from any lack of interest on the part of scientists or even the administrators but because of a lack of knowledge at many levels of government of the potential benefits of research and resultant production to the country. In other words, there must be dedication to food production at all levels.

Assuming now that food production is a priority item, what can CIMMYT do to help? Firstly, at the government's request, it can try to assist in securing funds from funding agencies to meet part of the financial burden within the framework of the National Program. Usually this is that part of research costs that must be met by foreign exchange. Once this is found, it may seem desirable to appoint CIMMYT personnel to assist in the organization of the research base and the ensuing production programs. CIMMYT can provide a practical training base for young scientists, assist in identifying those who should be trained to a higher degree level, and help to find funding to support such educational programs. Its personnel from the base program can and do visit with the national programs to provide advice, based on their experience elsewhere, on problems that arise as the program develops. They can also provide genetic materials from the base program in Mexico or facilitate exchange with scientists in other countries.

We believe that all of our base scientists and those in outreach country programs should gain wide experience in the crop with which they are dealing as early as possible. As a result of this policy, all of our base scientists have travelled to the major countries involved with a particular crop with which these scientists are working directly. Without a thorough knowledge of the problems for which they are seeking a solution in support of country programs, their abilities to work toward such solutions are much impaired. All of our outreach scientists are encouraged to attend regional and base-held meetings. When a particular CIMMYT outreach scientist has special knowledge in a particular field, we will send him to another country as a special consultant. In other instances we will arrange to have outside consultants brought in to help solve a specific problem or advise on approaches that should be taken.

Once a program is under way and is developing its own materials, the flow of germ plasm is a two-way street. In the country program, material sent from CIMMYT is reselected under the differing selection pressures of that country. Each of these selections will differ in many characters according to the intensity of selection to which they are subjected. These materials are then circulated back to the CIMMYT program and reincorporated by crossing into what Dr Borlaug calls the "genetic soup," which comprises the CIMMYT germ plasm pool. This again is sent back out to be reselected. Wider adaptation continues to develop when this process is continued either for disease resistance, weather, or other criteria.

It is natural that as numbers of country programs develop, some with direct CIMMYT personnel involvement and others with the assistance of other agencies, certain problems emerge that are common to all programs. One of the first of these is pathology, particularly that of the airborne pathogens. Another of regional nature is the coordination of distribution of materials within a region. Another might be entomological problems or agronomic problems of extensive application in a region. Still others may be training program activities within a region. At this point it is undoubtedly better to set up regional activities that will more closely and better service the region, than attempting to do this from some central point such as CIMMYT, but for coordination sake CIMMYT must have technical responsibility. These activities also serve to tie together the various national programs into a supra-national grouping. With their combined research strength, all of the countries in that group will benefit from each others active research.

Training

As outlined earlier, CIMMYT will provide a type of practical training that we hope will give young scientists a good appreciation of what is required to carry out a successful breeding program. Others will receive correspondingly greater involvement in pathology training. Still others will spend more time in quality determination in the laboratory or in other instances will learn how to conduct basic agronomic trials or production demonstrations in farmers' fields. These courses, where scientists work alongside our senior staff in the field, equip these young people to join as dynamic members of the research team in their home country.

CIMMYT also takes an active interest in arranging funding for outstanding young people whom they consider would be better equipped to help their national program with an advanced degree.

Once these young people are trained and absorbed back into national programs, we feel that governments should be sufficiently wise to place them in positions where their education will be best utilized. Further, they should receive salaries adequate to give them incentive and hold them in those positions. Unfortunately, this is seldom the case. We find scientists, sometimes with Ph.D. degrees, who are paid less than the average bellhop in a hotel in his own country. In my opinion, such a policy is short-sighted, and should raise distinct questions in the mind of CIMMYT or other institutions subsidizing such training or education, on the advisability of continuing to train people for that country.

Another area that thus far has received no attention is the training done at the undergraduate level in the national universities. Too often professors have been cut off from new ideas and new procedures. Their teaching is outdated, dry, irrelevant, and according to textbooks rather than common sense approaches. Would it not be useful to provide some funding for financing sabbatical years to send out some of the older and hence more powerful professors for refresher courses in their particular disciplines? Then we could expect to find bright young people with a well-trained background when we go in search of these for trainee positions. This is not an area in which CIMMYT is directly involved. Perhaps it is not CIMMYT's business, but it would certainly make our task easier in imparting our type of training in support of the programs.

Within regions and at our base in Mexico, we have been involved in holding various seminars. We feel that these seminars and conferences are very valuable as long as they are focussed on specific problem areas and deal with them in depth. For example, at this present meeting, jointly sponsored by the University of Manitoba and CIMMYT, we hope that much of the present knowledge gained by the various triticale research programs can be brought together and pooled. More important in our view is that this knowledge will be transferred from one scientist to another so that each will be wiser. We also hope that the young scientists from different countries who hold responsible positions in their national programs will get to know one another, develop mutual respect, and forge those links of friendship that will assist in the exchange of ideas and materials. This latter benefit is probably more important than simply amassing the present knowledge.

Problems in the National Programs

These programs are beset by most of the stumbling blocks that can be placed in the way of progress. Sometimes funding is insufficient, salaries are generally low, or scientists are unable to communicate except through tortuous official channels with officials in their own ministry, planning commissions, or other offices. Foreign exchange is not provided for even the smallest needs that are not available in the country. If the scientist travels, his per diem is miniscule. It costs him so much money he stays at home. These and a thousand other frustrations stand in his way. Finally, if in spite of all of these, the program by some means is successful, someone is bound to say that the contribution of research is rather minor and he, the researcher, therefore, should not be recognized. Further, that since he was able to operate on nothing, it is obvious that he should continue to operate on nothing, so that available funds can be plowed into some other sink without bottom that has had a long history of failure and every expectancy of continuing in the same line. This may seem like a dismal picture, but it is part of the reality that I see on every side in my travels to the various countries, both developing and developed.

Based on this, as a background of experience, it has been my observation that when expatriate personnel are assigned within a country program, they can perform certain functions not open to the national scientist. Hopefully, they can assist as an experienced scientist in the development of the research programs. In many ways they perform an ever greater service in being the treasurer and source of a very small amount of accessible money that can be called upon for those items that spell either success or failure of the program. For example, a small item such as the filters for a Udey protein analyzer can only be purchased with foreign exchange. No foreign exchange is available. He buys the filters and the equipment continues to function. The list is virtually endless, but these are the things, minor as they may be, upon which the program succeeds or fails.

Some funding agencies have traditionally considered that a program should function in virtually all respects on the local currency except for major items or payment of salaries of personnel appointed from without. Often large amounts of money are spent to support an expatriate scientist in the country program, but he is not provided with free funds to use in just such a situation as I have described above. I cannot stress too much the importance of this aspect. It cannot be covered by a grant made to most governments because once it has disappeared into the bureaucratic system, it cannot be retrieved without the same difficulties as are experienced in retrieving their own funds. Thus, some way must be found in each assistance grant to take care of this most important feature.

The Triticale Outreach Program

Turning specifically to triticale, I would like to give some indication of the growth of outreach that has occurred. In materials, about 30 nurseries were distributed in 1969, the year in which the first International Triticale Yield Nursery was sent out. (Smaller distributions of material had been made earlier on a nonorganized basis where specific requests were answered.) In 1970, 52 nurseries were circulated; in 1971, the total had risen to 82; in 1972 it was 133, and in 1973, 208 were distributed.

This increase in distribution has resulted from much increased interest because of the better types of triticale available (in height, fertility, seed type, and yield), a wider knowledge gained of its potential for nutrition, possible use on dry lands, and interest in the crop because it is new. During the same period, several countries have begun serious research. India now has several centres actively working with triticale. Pakistan has two centres; Algeria wants to mount a program as part of their cereal improvement; Kenya has one man appointed on triticale research; Ethiopia is seriously interested in using this crop commercially. Many others are at a point where they are awaiting further improvements before launching a full-scale program. This, I would say, is wise, since in most instances scientific manpower is very limited. In this connection I do not wish to ignore the well-advanced programs in such developed countries as Sweden, Spain, Hungary, the USSR, and the United States. The Canadian program, principally centred at the University of Manitoba, is considered jointly with that of CIMMYT. My remarks are confined to the programs in developing countries with which we are closely associated.

I feel that CIMMYT will not have to work at expanding the outreach of materials. The triticales have been distributed to many countries in all inhabited continents. The speed with which they were accepted is no doubt due to the fact that CIMMYT's bread wheat program had already established connections with those countries.

On the training front, three scientists have been specifically trained within the triticale program at the request of their governments in the past year. This, undoubtedly, will expand as it becomes more widely known that triticale training is available. As the country programs begin to proliferate, there will be need for financial assistance to some of those countries where it has proven to be successful. In the meantime, certain characteristics of triticales need to be improved and further research done to solve certain problems. As the triticales become more widely adapted and better characterized, I see them filling needs within each country on an equal footing with the other major cereals. I consider that farmer demonstrations should be conducted in countries such as India and Ethiopia where their value has already been shown at least for some ecological conditions.

In Lebanon, empirical observations indicate that triticales have greater resistance to moisture stress than spring bread or durum wheats; in Ethiopia, triticales give higher yields than bread wheats at many locations and in this case waterlogging of the soil is widespread; in India, yields are superior to those of wheat in mountainous tracts and this is thought to be due to better acceptance of low soil pH; in Brazil, triticales have been shown to have greater resistance to *Septoria* than the better wheats.

Other countries may not want to mount full-scale programs, but use their limited manpower on the proven cereals until triticales have been more fully developed. In the meantime, each country that is interested in this crop should grow the nurseries, become familiar with the crop, stay abreast of the improvements being made, and at that point when they are confident that this is a crop suitable for their production, give it full status as a new cereal crop.

It is my feeling that although there will be a wave of specialized products produced particularly in the developed countries, the main acceptance for triticale will come from its ability to yield as well as the other cereals. It will not be sold on its superior quality but on equal or greater returns. In the countries with which we deal, the uses are likely to parallel those of the other cereals. Aside from this, triticales may well perform in a superior way in certain ecological conditions. Should it be able to spread into the dryer areas and give better results than wheat or barley, it would be accepted on this basis.

I am sure that triticale is now at the point of its coming of age. The major problems that prevented it from being immediately suitable to production seem to have been overcome. In reaching this position the germ plasm had to be narrowed. It is indeed surprising that the materials presently available are as widely adapted as they appear to be. Its basic germ plasm is now being rapidly expanded.

I would expect that within the next 3–5 years several additional varieties may find a place in commerce. As the germ plasm base is widened, wider adaptability will be incorporated and varieties then may grow successfully over much of the cereal acreage of the world.

Meiotic, Gametophytic, and Early Endosperm Development in Triticale

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BENNETT, MICHAEL D. 1974. Meiotic, gametophytic, and early endosperm development in triticale, p. 137–148. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Sterility in triticale may have several causes, including failure of meiotic and gametophytic development in either the anther or ovary, and failure of either embryo or endosperm development. Results are described showing that, in particular, failure of normal development in the ovary and the total abortion of early endosperm development contribute to sterility in triticale. Observations of nuclear and cellular behaviour are described in the young endosperm of Rosner triticale that are correlated with its total abortion (and hence sterility) in some florets, and may be correlated with the production of shrunken grain in other florets. A simple method is described for distinguishing between the chromosomes of rye (*Secale cereale*) and wheat (*Triticum aestivum*) in an octoploid triticale derived from them. There was a striking structural difference between the polynemic chromosomes of wheat and rye in mature antipodal cell nuclei. Each rye chromosome, but no wheat chromosome, had a prominent dark-staining body at one or both telomeres. The number and distribution of the dark-staining telomeric bodies in polynemic rye antipodal chromosomes appear to correlate with the number and distribution of telomeric Geimsa-staining bands in rye root-tip metaphase diploid chromosomes. The possible basis of genome incompatibility in triticale is discussed.

Résumé La stérilité du triticale peut avoir plusieurs causes, dont les accidents au cours de la méiose ou de l'évolution du gamétophyte, dans l'anthère, ou dans l'ovaire, et le non développement de l'embryon ou de l'endosperme. Selon les résultats des recherches, on constate notamment que le développement anormal de l'ovaire et l'avortement total du développement premier de l'endosperme contribuent à la stérilité chez le triticale. Selon les observations faites sur le comportement des noyaux et des cellules de l'endosperme jeune du triticale Rosner, ce comportement a un lien avec l'avortement total (et par conséquent la stérilité) de certaines fleurs, et peut en avoir un chez d'autres fleurs avec la production d'un grain ratatiné. L'auteur décrit une méthode simple permettant de reconnaître les chromosomes du seigle (*Secale cereale*) et ceux du blé (*Triticum aestivum*), dans un triticale octoploïde qui en est issu. On a constaté une différence structurale frappante entre les chromosomes polynémiques des noyaux d'antipodes adultes du blé et du seigle. Un ou deux télomères de chaque chromosome du seigle comportent une excroissance prenant une couleur sombre, mais non ceux du blé. Il semble que le nombre et la répartition de ces excroissances télomériques des chromosomes polynémiques des antipodes du seigle soient liés au nombre et à la répartition des bandes télomériques se colorant au giemsa des chromosomes diploïdes observés dans les méristèmes radiculaires du seigle lors de la métaphase. Le texte traite également de l'incompatibilité possible des génomes dans le triticale.

Two major problems have been encountered in triticale breeding. First, most allopolyploid triticale cultivars are "subject to reproductive disorganisation characterised by premature desynapsis of meiotic bivalents and aneuploid or inviable gametes" (Rupert et al. 1973). These result in sterility in some florets and consequently in reduced grain yield. Second, "triticale shows varying degrees of seed shrivelling" (Darvey 1973), and this too results in reduced grain yield. Cytological investigations of triticale chromosomes have been hampered by the lack of simple methods for distinguishing between wheat and rye chromosomes in somatic and meiotic cells. Rye chromosomes can be identified in a test plant from an analysis of chromosome pairing behaviour in F_1 plants obtained from crosses of the test plant with either wheat or rye (Gustafson and Zillinsky 1973; Mettin et al. 1973). A method for identifying rye chromosomes based on karyotype analysis of metaphase chromosomes in somatic cells has been suggested by Lelley (1973). Both methods are laborious and time consuming.

The objects of this paper are threefold: first, to describe observations of cell and nuclear behaviour in triticale possibly related to the causes of meiotic instability and grain shrinkage mentioned above; second, to describe a simple method for identifying the presence of rye chromosomes in test triticale and other genotypes; and third, to discuss briefly the possible basis of genome incompatibility in triticale.

Rates of Cell Development in Wheat, Rye, and Triticale

Studies of the total duration of the cell cycle in root-tip meristem cells of wheat, rye, and hexaploid triticale have not revealed any important differences. The cell cycle time at 20°C lasted 12.5 h in wheat (*Triticum aestivum*) (M. W. Bayliss, unpublished data); 12.0 h in hexaploid triticale (Kaltsikes 1971); and 11.5 (Kaltsikes 1971) and 12.1 h (M. D. Bennett, unpublished data) in rye (*Secale cereale*). Apparently the rates of somatic cell development in wheat and rye species are very similar. Consequently, differences between the developmental rates of wheat and rye chromosomes are unlikely to be a cause of genome incompatibility during somatic cell growth in triticale. As far as I am aware, no aberrant nuclear behaviour in somatic cells of triticale has been reported.

Studies of the rates of reproductive cell development, however, have revealed important differences between wheat, rye, and triticale genotypes (Bennett and Smith 1972; Bennett and Kaltsikes 1973). At 20°C meiosis in the diploid wheat *T. monococcum* (42 h) was shorter than in diploid *S. cereale* (51 h). Similarly, in the tetraploid wheats *T. dicoccum* (30 h) and *T. turgidum* var. *durum* (31 h) meiosis was shorter than in tetraploid *S. cereale* (38 h). Moreover, meiosis in hexaploid *T. aestivum* (24 h) was shorter than in the two hexaploid triticales, Rosner (34 h) and 6A190 (37 h). Thus, at the diploid, tetraploid, and hexaploid levels, meiosis was longer in plants containing rye genomes than in plants containing wheat genomes alone. The existence of these differences might lead one to expect aberrant nuclear behaviour during meiosis in triticale. Gross differences between the rates of meiotic prophase development of wheat and rye chromosomes in triticale as reported by Schkutina (1969) and Stutz (1962) are rare. However, the difference between the rate of meiotic development of rye chromosomes in *S. cereale* and the rate of development of the same chromosomes in triticale might be a major cause of meiotic instability in triticale.

For example partial chromosome pairing failure in octoploid triticale may be caused by the difference between the durations of zygotene and pachytene in octoploid triticale and the durations required by rye chromosomes for normal meiotic behaviour (Bennett et al. 1971). Bennett and Kaltsikes (1973) also showed that in diploid and tetraploid rye and in hexaploid triticale the proportion of the total meiotic time taken by zygotene and pachytene together (about 40%) differed from the proportion of meiosis that they took in hexaploid wheat and octoploid triticale (about 25%). It was concluded, therefore, that such proportional differences may be causally correlated with differences in meiotic stability of rye chromosomes in triticales of different ploidy levels.

Female Meiosis and Embryo Sac Development in Triticale

In triticale, as in related species, each floret contains several hundred pollen mother cells (PMC) but only a single embryo sac mother cell (EMC). Consequently, meiotic failure in a single EMC inevitably results in a sterile floret whereas meiotic failure in a PMC merely reduces the number of pollen grains produced by four. Using nullisomic lines in *T. aestivum*, Sears (1954) showed that the absence of just a single chromosome can produce a high frequency of female sterility. Thus, the loss of even a single chromosome due to meiotic instability could cause female sterility in triticale.

Meiotic chromosomes behaviour and gametophyte development in triticale has usually been studied in anthers. However, because of the importance of female meiosis and embryo sac development, a pilot experiment to study these processes was carried out using an octoploid triticale (Chinese Spring × King II). Using the method described by Bennett et al. (1973), ovules were examined from florets at, or close to, anther dehiscence to see what percentage of embryo sacs had undergone normal development. In about 15% of the florets examined the embryo sac had failed to develop and the ovule contained only undifferentiated parenchymous cells. A further 10% of the embryo sacs contained no egg cell and the polar body consisted of three fused haploid nuclei instead of two (Fig. 1). Since the method used detected only grossly aberrant embryo sac development, the actual proportion of florets incapable of being fertilized was probably much higher than 25%. Detailed studies of the incidence of aberrant female meiotic and gametophytic development are needed so that the contribution of misdevelopment in these processes to the problem of sterility in triticales can be estimated.

Rates of Normal Endosperm Development

The rates of embryo and endosperm development were measured in plants grown at 20°C with continuous illumination (Bennett et al. 1973). In hexaploid wheat (Chinese Spring), diploid rye (Petkus Spring), hexaploid triticale (Rosner), and octoploid triticale (Chinese Spring × King II) the pollen tube penetrated the embryo sac about 30 min after pollination and sperm nuclei reached the egg nucleus and the polar nuclei about 40 min after pollination. Mitosis occurred in the primary endosperm nucleus about 6 h after pollination whereas in the zygote it occurred about 22 h after pollination. By 24 h after pollination the endosperm contained 16 or 32 nuclei in *T. aestivum* and *S. cereale*, whereas in the 6x and 8x triticales it contained 16 nuclei. Thus, the nuclear doubling times were very similar (between 4.5 and 5.5 h) in the endosperms of all four genotypes during this period.

During the first 5 days after pollination the pattern of endosperm development in rye and triticale is essentially similar to that described for *T. aestivum* var. Chinese Spring (Bennett et al. 1973). Initially the endosperm is coenocytic but after 3 days it becomes cellular. During the coenocytic phase nuclear development is highly synchronous but becomes progressively less so. The nuclear doubling time slowly increases from an initial time of 4.5–5.5 h to reach about 8–10 h by the onset of cell wall formation but thereafter it is greatly increased. The rates of embryo and endosperm development in florets of *T. aestivum* and hexaploid triticale Rosner with normal development were very similar (Table 1).

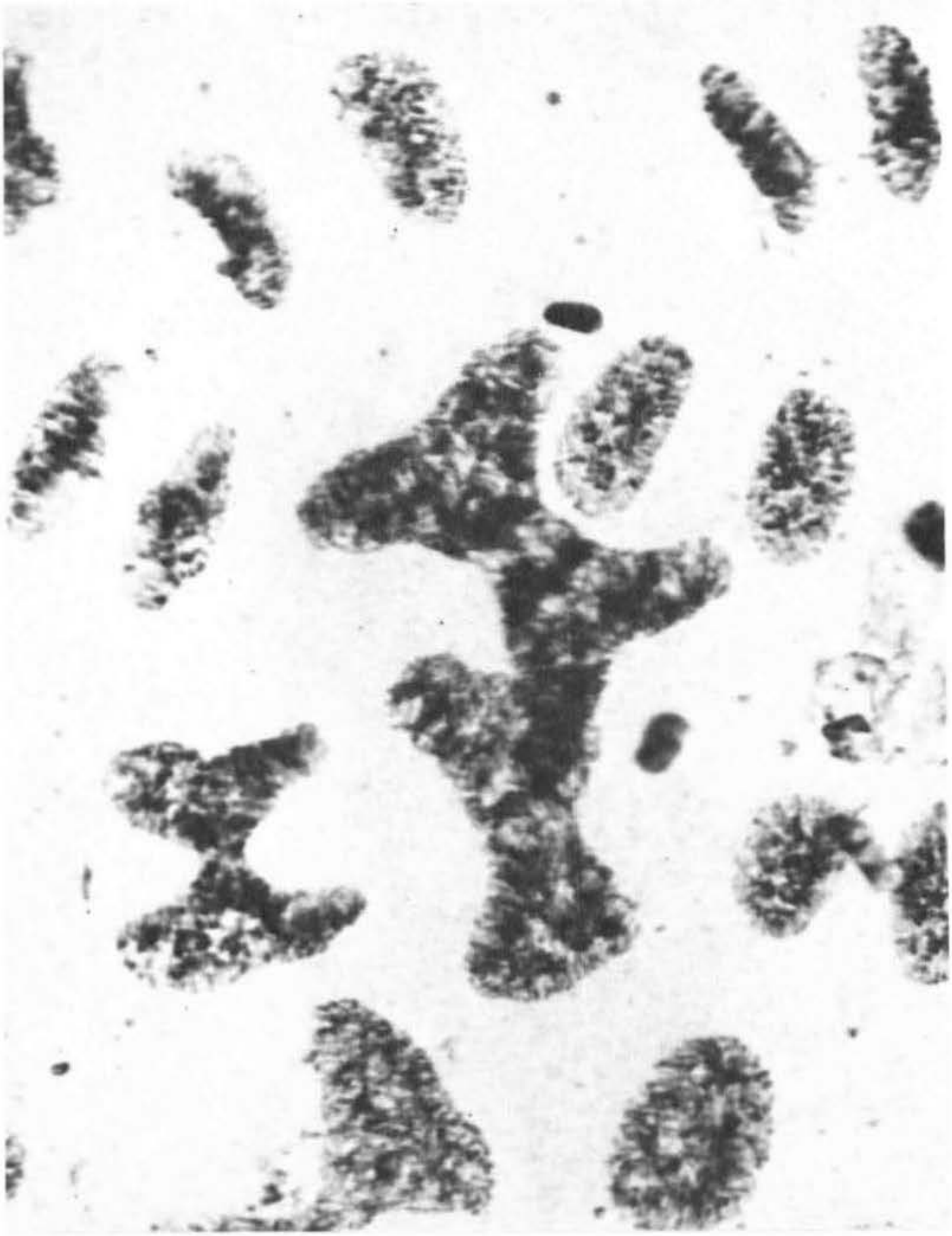

FIG. 1. Feulgen-stained Rosner triticale endosperm nuclei fixed 72 h after pollination. Normal nuclei, polyploid butterfly-shaped nuclei, and micronuclei are seen. Note the bridge of chromatin joining one pair of otherwise normal nuclei.

TABLE 1. Mean number of embryo and endosperm cells (or nuclei) at various times after pollination in hexaploid wheat and triticale grown at 20°C with continuous illumination.

	Genotype			
	Triticum aestivum (Chinese Spring)		Triticale (Rosner)	
Days after pollination	Embryo	Endosperm	Embryo	Endosperm
1	2	16	2	16
2	8	276	4	128
3	16	876	15	1024
5	232	>10,000	153	>10,000

Aberrant endosperm nuclei containing more than the normal 6*C* DNA content occur at low frequencies in developing endosperm sacs of many cereal species (Moss 1970) especially in the neck of the endosperm near the proembryo. Examination of feulgen-stained endosperm sacs from florets fixed 3–4 days after pollination revealed the presence of a few such nuclei in some endosperms of Chinese Spring, Petkus Spring, and Rosner. The incidence and size of such nuclei was greatly increased in a significant number of florets in Rosner triticale but never in hexaploid wheat or diploid rye. A detailed study of the development of aberrant polyploid nuclei in Rosner endosperm was made.

Aberrant Endosperm Development in Rosner Triticale

In normal Rosner endosperm the nuclei remain synchronous in development until the 512 nuclear stage reached about 64 h after pollination. By 24 h after pollination a few Rosner endosperms exhibited abnormally asynchronous nuclear development, and by 48 h after pollination some endosperms displayed pronounced asynchronous nuclear development. Such asynchrony was never observed in Chinese Spring wheat or Petkus Spring rye, and did not occur in most florets of Rosner triticale. Aberrant polyploid endosperm nuclei were first observed in Rosner endosperms fixed 48 h after pollination. They were larger than the normal triploid endosperm nuclei and contained up to four times the normal 6*C* DNA content. Aberrant nuclei were sometimes sub-spherical but usually they were butterfly- (Fig. 1) or dumbbell-shaped and composed of two equal or unequal chromatin masses joined by one or more chromatin bridges (Fig. 2). At increasingly later times, between 48 and 120 h after pollination, aberrant endosperm nuclei were detected with increasingly greater sizes and DNA contents. Some endosperm sacs fixed 96 or 120 h after pollination contained one or two giant aberrant nuclei with at least 100 times the normal 6*C* DNA content of endosperm nuclei (Fig. 3). Some of these giant aberrant nuclei were so large as to be visible to the naked eye in feulgen-stained embryo sacs dissected from florets fixed 5 days after pollination. Observations of endosperm sacs containing giant aberrant nuclei showed that the remainder of the normal endosperm nuclei had either already aborted and disintegrated, or were in the process of doing so. The development of the associated proembryo was normal, however. It was concluded that the presence of giant aberrant nuclei causes the death of the endosperm but not necessarily of the embryo.

Aberrant nuclei, usually in groups, were observed throughout the endosperm. They were, however, most often found in the neck of the endosperm just below its junction with the proembryo. Cell wall formation often occurred later in normal endosperms than in endosperms containing aberrant nuclei with 2–16 times the normal DNA content. Thus, in florets fixed 72 h after pollination, cellular endosperms were found that contained 256–512 cells including some with aberrant nuclei. Normal endosperms contained about 1024 nuclei and were not yet completely cellular at this time.

Polyploid endosperm nuclei are formed after either the omission of mitosis between successive phases of DNA synthesis, or failure of anaphase during mitosis. The latter was frequently observed in Rosner triticale; how-

FIG. 2. A feulgen-stained Rosner triticale endosperm nucleus fixed 72 h after pollination. Two daughter nuclei that failed to separate at the previous telophase remain attached by several strands of chromatin.

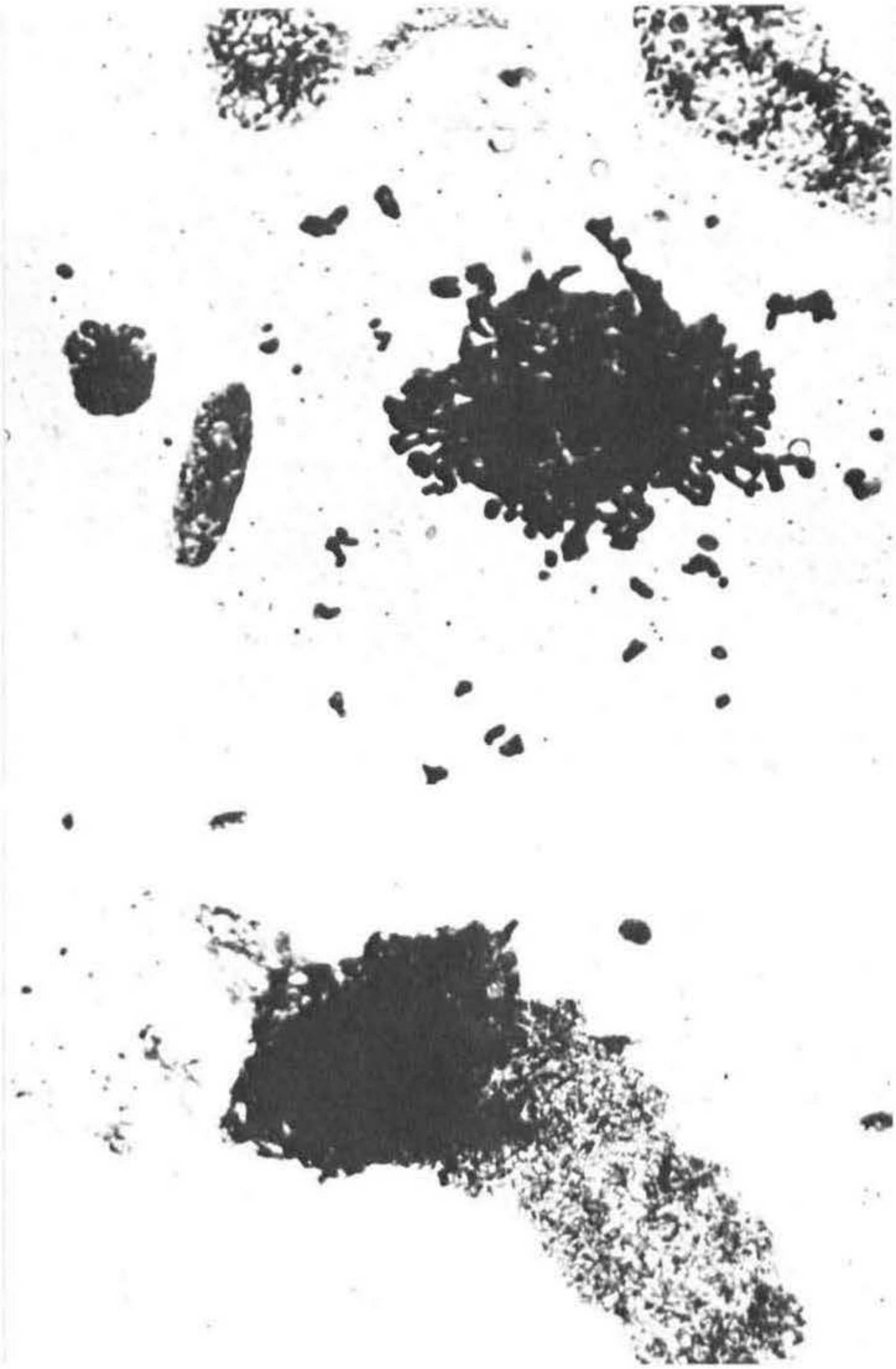

FIG. 3. Feulgen-stained Rosner triticale endosperms fixed 96 h after pollination showing an abberrant polyploid restitution nucleus containing about eight times the normal 6C DNA content (*top*), and a giant restitution nucleus containing at least 100 times the normal 6C DNA content of endosperm nuclei (*bottom*). Traces of aborted normal endosperm nuclei are seen.

ever, the former may also have occurred. Bridges connecting partially separated daughter nuclei formed at mitosis were often seen in the coenocytic endosperm of triticale. The formation of bridges between nuclei at telophase in a coenocytic tissue has different consequences for further development than their formation in a cellular tissue. In a cellular tissue, the bridges would be pinched off by the developing cell wall and the daughter nuclei would be isolated in single cells. In a coenocyte, however, the bridges remain unbroken so that restitution nuclei with double ploidy level are formed. Furthermore, the aberrant nuclei produced in endosperms are not isolated from normal nuclei by cell walls, nor from the supply of metabolites necessary for their further development.

Observations of aberrant nuclei in Rosner showed that once produced they continued to undergo DNA synthesis at normal intervals. Consequently, their size and DNA content doubled with each successive round of DNA synthesis. Thus an increasingly abnormal product of a single misdivision remained unisolated from normally developing endosperm nuclei until the time of cell wall formation. It seems, therefore, that the time of the initial misdivision during the coenocytic stage is important in determining its effect on subsequent endosperm development. If the initial misdivision occurs early in the coenocytic stage, so that many rounds of DNA synthesis are completed before cell walls are formed, then the resultant giant polyploid nuclei causes the death of the endosperm. If, however, the initial misdivision occurs late during the coenocytic stage, so that only a few cycles of DNA synthesis are completed before the aberrant nucleus is isolated by a cell wall, then the death of the entire endosperm need not result. Instead, the cells with polyploid endosperm nuclei may themselves die. Thus, in cellular endosperms fixed 120 h after pollination, patches of cells containing dead or aborting aberrant polyploid nuclei were seen, yet the surrounding cells appeared to be developing normally. The death during early seed development of a patch of endosperm cells would presumably result in reduced later development of a part of the endosperm. It is suggested, therefore, that the death of patches of cells with aberrant nuclei formed late in the coenocytic stage might be a cause of shrunken endosperm in triticale. Further experimental investigations of this hypothesis are required and are being undertaken at Cambridge.

The production of polyploid nuclei during the coenocytic stage of endosperm development is certainly a cause of sterility and may be a cause of shrunken grain in triticale and may therefore be the principal factor causing both the major problems facing triticale breeders.

The cause of aberrant polyploid nuclear development in endosperm appears to be the development of abnormal asynchrony between adjacent nuclei within the coenocyte. Such asynchrony can, and sometimes does, develop in the coenocytic endosperm of most cereals and results in the production of polyploid nuclei. However, in triticale it occurs earlier in development, and in a greater proportion of florets than in wheat or rye, probably because of increased stresses caused by genome incompatibility during coenocytic development in triticale compared with established nonhybrid genotypes.

Cytological Identification of Rye Chromosomes

Use of Antipodal Cell Nuclei

Bennett et al. (1973) made a detailed study of the development of antipodal cells in the embryo sac of *T. aestivum* var. Chinese Spring. In plants grown at 20°C the chromosomes in antipodal cell nuclei became highly polynemic during the 5 days prior to anther dehiscence. During this period the DNA content of antipodal cell nuclei increased from the haploid (2*C*) amount to between 64 and 256*C* amounts. In feulgen-stained ovules fixed shortly after pollination, each of the 21 chromosomes could be counted in some squashes of antipodal cells. Each polynemic chromosome consisted of a dense darker staining centromeric region with chromosome arms formed of less dense, loosely organized bunches of feulgen-positive threads on either side. In intact, unsquashed, antipodal cell nuclei the chromosomes were always arranged in a constant pattern which the nucleus. The 21 denser centromeric regions were located at one pole of the nucleus whereas the less dense chromosome arms radiated toward the opposite pole over and around the centrally located nucleoli. Although the centromeric thickenings were denser than the chromosome arms, they were nevertheless completely composed of feulgen-positive threads.

Studies of antipodal nuclei in rye (*S. cereale* var. Petkus Spring and Prolific) revealed a similar pattern of antipodal cell development to that found in wheat. However, a marked difference was observed between the appearance and distribution of DNA in polynemic chromosomes of wheat and rye. Unsquashed antipodal cell nuclei from newly fertilized embryo sacs of rye contained not only the haploid number (7) of darkly stained centromeric regions grouped at one pole of the nucleus but also at least eight and sometimes nine spherical or sub-spherical feulgen-positive, heteropycnotic bodies. The bodies ("rye bodies") were located at, or near, the ends of the chromosome arms and hence near the opposite pole of the nucleus from that near the seven centromeric regions. Squash preparations of feulgen-stained antipodal cell nuclei showed that these bodies differed from the centromeric regions in several obvious respects. The rye bodies were denser and darker staining and had a more distinct outline; they were spherical or sub-spherical and appeared to be solid rather than composed of threads; often, however, they contained one or more small unstained vacuoles. The most obvious difference between the rye bodies and centromeric regions was that the rye bodies were located at or near telomeres whereas the centromeric regions were of median position. Estimates of the DNA content of the rye bodies showed that they each contained up to about 4% of the haploid rye genome so that together they may contain about 32% of the nuclear DNA.

It seemed possible that the presence or absence of rye bodies might prove useful in establishing a method for identifying the presence of rye chromosomes in triticale. The distribution of rye bodies was investigated in mature feulgen-stained antipodal cell nuclei of various wheat, rye, triticale, and other genotypes. The following results were obtained:

1 Rye bodies do *not* occur in hexaploid wheat (*Triticum aestivum* var. Chinese Spring and Holdfast). They *do* occur in some other diploid, tetraploid, and hexaploid wheats.

2 The presence of up to eight or nine rye bodies was demonstrated in several plants of *Secale cereale* var. Petkus Spring and Prolific and also in *S. montanum*. Observation of autotetraploid *S. cereale* revealed the presence of up to 16 rye bodies in antipodal cell nuclei.

3 Both a hexaploid triticale (Rosner) and an octoploid triticale (Chinese Spring × King II) were examined. Up to eight rye bodies were observed in antipodal nuclei of the former (containing 14 wheat and seven rye chromosomes) and the latter (containing 21 wheat and seven rye chromosomes). The development of rye bodies is therefore not suppressed in triticale hybrids.

4 Antipodal cells were examined from each of the seven disomic addition lines of known King II rye chromosomes to Holdfast breadwheat. In these plants the haploid antipodal nuclei should contain 21 wheat chromosomes plus a single known rye addition chromosome. It was shown that antipodal cells of each of the seven rye addition chromosomes contained a single obvious rye body, with the exception of addition chromosome V, which contained two rye bodies. In this way it was established that each rye chromosome bore a single large rye body, with the exception of chromosome V, which bore two. Furthermore, observations in rye addition line plants showed that each rye body was located at, or very near, the telomere of one chromosome arm. On chromosome V, however, one rye body was apparently located at the end of either chromosome arm.

5 Antipodal cells were examined from each of the available ditelocentric addition lines of King II rye chromosomes to Holdfast wheat. Unfortunately, ditelocentric addition lines were available for only one arm of chromosomes V, VI, and VII. Results obtained (Table 2) for six out of the seven rye chromosomes agree with those obtained for whole addition chromosome lines. Thus, rye bodies are located on the short arm of chromosomes I, II, and IV but not on the long arm. Presumably rye bodies are located on the short arm but not the long arm of chromosome VII, and on the long arm but not the short arm of chromosome VI, and one on each arm of chromosome V. The results obtained for telocentrics of the supposed α and β arms of chromosome III were unexpected, since both apparently carried a single rye body. The significance of this result will remain unclear until further tests have been carried out on further ditelocentric lines for both arms of this chromosome.

TABLE 2. Distribution of rye bodies in ditelocentric addition lines of King II rye chromosomes to Holdfast wheat.

Chromosome no.[a]	Long arm[b]		Short arm[b]	
	Genotype	No. rye bodies	Genotype	No. rye bodies
I	(C3)	None	(C17)	1
II	(A24)	None	(H1/6/23)	1
III	(T3)	1	(H2/11)	1
IV	(G25/30)	None	(G25/17)	1
V	(24B/48)	1	–[a]	–
VI	–[a]	–	(H3/4)	None
VII	(H1/16/L)	None	–[a]	–

[a]The numbers of rye chromosomes are those given by Riley (1960).

[b]Chromosomes III and V have telocentrics that are not distinguishable as long or short. For these two chromosomes the α arm is arbitrarily placed with the long-arm telocentrics of the remaining chromosomes.

Use of Giemsa Stain

Giemsa staining techniques have been developed recently that reveal characteristic banding patterns in plant and animal chromosomes (Pardue and Gall 1970; Schweizer 1973) and that, therefore, are useful for karyotype analysis. It seemed reasonable to investigate whether the presence of the chromatin that forms the rye bodies in polynemic chromosomes of antipodal cells could be demonstrated in diploid somatic cells using the Giemsa techniques mentioned above. Although only preliminary results are available it seems useful to mention them here.

Using root-tip meristem cells treated with a Giemsa staining technique (modified from Vosa and Marchi 1972) the following results have been obtained: (*1*) no Giemsa bands were detected at the telomeres of any chromosome in hexaploid wheat (Chinese Spring) chromosomes; however, dark-staining Giemsa bands were found in diploid rye (Petkus Spring) chromosomes; (*2*) all the Giemsa bands seen in rye chromosomes were located at the telomeres; and (*3*) most rye chromosomes had a Giemsa band at only one telomere; however, up to four chromosomes per cell were observed that had Giemsa bands at both telomeres.

Further experiments are being conducted to determine the distribution of Giemsa bands within the rye karyotype using addition lines of King II rye chromosomes to Holdfast wheat. It seems possible from the preliminary results that the distribution of Giemsa bands in rye diploid somatic chromosomes may be the same as the distribution of rye bodies in polynemic rye antipodal cell chromosomes.

The presence of distinct rye bodies on one or both telomeres of each rye chromosome but not of any *T. aestivum* wheat chromosome may offer a simple screening method for determining the presence or absence of whole rye chromosomes in triticale and other genotypes and also perhaps for counting the number of rye chromosomes. Furthermore, the presence of two rye bodies on chromosome V may allow this chromosome to be distinguished from other rye chromosomes.

Each floret in triticale contains about 20 or 30 antipodal cells and these are available for investigation for at least 48 h starting from anther dehiscence. Compared with first metaphase of meiosis, which lasts less than 2 h at 20°C (Bennett and Smith 1972), antipodal cell nuclei are more readily available for study.

Basis of Genome Incompatibility

It has already been noted that the DNA content of the diploid rye genome is much greater (by about 34%) than the largest diploid genome in hexaploid or tetraploid wheat. Furthermore, the rye chromosomes have a higher mean DNA content than wheat chromosomes. It has also been shown that the distinctive chromatin that forms the rye bodies may constitute about 32% of the total rye genome. It is possible that much of the extra DNA possessed by rye compared to diploid wheat is contained in the rye bodies located at eight or nine of the 14 telomeres in the haploid rye complement.

Comparison of cell cycle studies in wheat and rye shows that the mean percentage of the cell cycle taken by DNA synthesis (S) is about one-third longer in rye than in wheat (Bennett, unpublished data). It has been shown (Lima-de-Faria and Jaworska 1972) first, that in diploid rye the duration of S is proportional to chromosome length, and second, that the last third of the S phase involves DNA synthesis occurring only at the telomeres in what is probably heterochromatin (Lima-de-Faria and Jaworska 1972; Darlington and Hague 1966). Ayonoadu and Rees (1973) recently suggested that only one telomere on each chromosome in rye is heterochromatic.

The distribution of cytologically distinct chromatin forming rye bodies is apparently identical with that of late-replicating heterochromatic DNA segments in rye chromosomes. Wheat chromosomes bear neither rye bodies nor obvious heterochromatic segments at their telomeres. It is suggested, therefore, that genome incompatibility in triticale, manifested both in meiocytes and coenocytic endosperm, is caused by the presence of a large segment of late-replicating heterochromatin at the telomeres of rye chromosomes but not of the much smaller chromosomes of wheat.

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Metabolic Factors Influencing Kernel Development in Triticale[1]

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HILL, R. D., A. J. KLASSEN, AND W. DEDIO. 1974. Metabolic factors influencing kernel development in triticale, p. 149–154. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Analysis for α-amylase activity in eight triticale cultivars varying in their test weight indicated a significant correlation (r = –0.909*) between amylase activity and grain density. Starch content was positively correlated with test weight (r = 0.746*). Starch deposition in some shrivelled cultivars was slower and the maximum starch content per unit of kernel volume was lower than in plump-seeded cultivars. Sucrose–^{14}C feeding experiments indicated that the shrivelled triticale cultivar, 6A190, was less efficient at transporting sucrose to the head than the plump cultivar, 6531. In addition, 6A190 deposited a larger proportion of the transported sucrose to the pericarp than 6531. Studies on the development of α-amylase during maturation showed that α-amylase activity in four triticale cultivars reached a maximum within the pericarp at approximately 12–15 days and declined to a minimum at approximately 20 days. Aleurone and endosperm α-amylase increased from approximately 20 days to a maximum at 28–32 days in all varieties except 6A190. In 6A190, α-amylase continued to increase as the grain matured, reaching levels that are characteristic of malted grains.

Résumé L'analyse de l'activité de l'alpha-amylase dans huit cultivars de triticale différant quant au poids lors des essais a indiqué une corrélation significative (ν= —0.909*). Chez certains cultivars à grain ratatiné, l'accumulation d'amidon etait plus lente et la teneur maximale en amidon était plus faible par unité volumétrique de grain que chez les cultivars à grains pleins. Des essais d'alimentation en saccharose-^{14}C ont indiqué que le cultivar de triticale ratatiné 6A190 transportait le saccharose vers l'épi moins efficacement que le cultivar plein 6531. De plus, chez 6A190, une proportion plus importante du saccharose transporté se déposait dans le péricarpe que chez 6531. L'étude du développement de l'alpha-amylase au cours de la maturation a montré que pour quatre cultivars de triticale son activité atteignait un maximum dans le péricarpe au bout de 12–15 jours environ puis déclinait jusqu'à un minimum pendant 20 jours à peu près. L'aleurone et l'alpha-amylase de l'endosperme augmentaient à partir du 20e jour jusqu'à un maximum au bout de 28–32 jours pour toutes les variétés à l'exception de 6A190. Chez ce dernier, l'alpha-amylase continuait d'augmenter au fur et à mesure que le grain mûrissait, atteignant les niveaux qui caractérisent les grains maltés.

[1]Contribution No. 383 from the Department of Plant Science, The University of Manitoba, Winnipeg, Man., Canada R3T 2N2.

ALTHOUGH the synthesis of triticale has presented an opportunity to combine the high quality characteristics of wheat with the hardy competitive traits of rye, it has also introduced some of the poor quality characteristics of rye. Two of these characteristics are shrivelled kernels and high α-amylase activity. Kernel shrivelling in hexaploid triticales was first documented by Sanchez-Monge (1958). Reports from a number of sources indicate that mature triticale grain is higher in α-amylase activity than sound wheat (Müntzing 1963).

These and other observations have led us to investigate possible correlations between grain shrivelling and amylase activity in some triticale lines, the rationale being that either α-amylase caused breakdown of starch to produce shrivelling or that it was an indicator of pre-germination in the seed. This pre-germination could cause cessation of maturation processes resulting in seed shrivelling.

Materials and Methods

Plant Materials

For studies on relationship between α-amylase activity, grain density, and starch deposition during maturation, samples were grown under field conditions at Winnipeg during the summer of 1968. Spikes of all lines were tagged at the time of anther extrusion and six spikes of each line were harvested at each of seven different stages of maturity beginning 10 days after initiation of flowering and at weekly intervals thereafter.

For studies on the development of α-amylase during maturation, samples of triticale cultivars 6A190, 6A250, Beaver 'S' (E_1-68B-5N), and Kangaroo × UM940 'S' (X1005-10M-1Y-3M-3Y 0M) were grown in the greenhouse during the winter of 1972–73. At anthesis the spikes were tagged and from 6 to 42 days post-anthesis the spikes were harvested at 4-day intervals and stored at –20°C.

α-Amylase Analysis

Two methods of α-amylase analysis were used. In the studies using material from 1968, a viscometric method described by Tipples (1969) was used. In subsequent studies the method of MacGregor et al. (1971) was more sensitive and was used with some modification on material grown during 1972–73. The procedure was as follows.

At the time of α-amylase analysis five seeds from the middle of the spike were separated into pericarp, embryo, aleurone layer, and endosperm. Another three seeds were taken for α-amylase analysis of the whole seeds. The samples were homogenized with acetate buffer at pH 5.5 and after 2–3 h centrifuged in a clinical centrifuge. Ten millilitres of buffer were used for whole seed and for pericarp analysis, 5 ml for the aleurone layers and endosperms, except in certain samples with high α-amylase activity where more buffer was used, and 2 ml buffer for embryo analysis. After centrifugation, the supernatant was transferred to test tubes, being careful not to disturb the sediment. The method for α-amylase analysis was similar to that of MacGregor et al. (1971) with certain modifications. For α-amylase–dextrin incubations the volumes were reduced by half, as this was sufficient to obtain absorbance readings. A 1-ml sample was prepared from 0.2 ml of extract and 0.8 ml of acetate buffer. For triticale samples the incubation period was reduced to 5 min with two aliquots taken from each sample. With each set of unknowns, four samples containing 1 ml dextrin, 1 ml buffer (instead of the extract, which contains only small amounts of starch), and 5 ml of iodine solution were prepared as standards.

Soluble Sugars

Soluble sugars were extracted from 50- to 100-mg samples of ground grain with 3-ml portions of cold 80% ethanol. After evaporation of the ethanol the residue was resuspended in 10 ml of distilled water. Reducing sugars were measured in the supernatant by the ferricyanide method of Guinn (1967) with glucose as the standard.

Starch

Starch was estimated by a modification of the method of Donelson and Yamazaki

(1968). Twenty-milligram samples of ground grain were suspended in 4 ml distilled water and the starch gelatinized by placing the test tubes in vigorously boiling water for 2 min. The tubes were then cooled rapidly to 30°C and 5 ml acetate buffer (pH 4.7) was added and placed in a 30°C water bath. One millilitre of α-amylase solution (0.020 g Mann α-amylase; 19,900 BU/g) was added and incubation carried out for 1.5 h and the enzymatic hydrolysis was stopped by the addition of 1 ml of 50% trichloracetic acid. After neutralization with NaOH, centrifugation, and appropriate dilution, reducing sugars produced by the hydrolysis were measured using the Guinn (1967) method. Pure Lintner starch (Fisher Scientific Co.) was used as the standard and corrections were made for free reducing sugars present in the samples before hydrolysis.

Results and Discussion

In the initial studies (Klassen 1970; Klassen et al. 1971) seven hexaploid triticale lines and one octoploid variety were analyzed for a number of parameters that could be related to shrivelling. Some of the results of these experiments are summarized in Table 1. Test weight varied from about 54 to 65 kg/hl for the triticales. This is considerably lower than Stewart 63 and Manitou wheats, which were included as controls. Some of the varieties approached Prolific rye in test weight. Seed volume has been included to give an indication of seed size since 1000 kernel weight does not always reflect seed size where severe shrivelling is present. For example, 6531 and 6211.2 have approximately the same seed volume, yet their 1000 kernel weight is 52.5 and 43 g, respectively. There was a highly significant statistical correlation of −0.909** between test weight and α-amylase activity among the lines studied. A 15-fold variation in the amylase activity of the triticales was observed with some varieties having almost 50 times the activity of the hexaploid wheat. There was no correlation between reducing sugar content and test weight but the level of reducing sugar in the seed did reflect the α-amylase activity. Starch content was positively correlated with test weight ($n =$ 0.746*) indicating that the loss in test weight was probably due to a decrease in the starch content of shrivelled seed.

The rate of starch deposition during maturation does vary from variety to variety. For example, Fig. 1 shows the starch content of four triticale lines and Manitou wheat at various stages of development. The initial slopes of the curves of the two lines of lowest bushel weight, 6211.2 and 6A190, are smaller than 6531 and 6A320, indicating that they have a slower rate of starch deposition. In addition, the maximum starch content per

TABLE 1. Characteristics of the mature grain of experimental lines.

Sample	Test weight (*kg/hl*)	Seed volume (*cc*)	α-Amylase[a] (*units/kernel*)	Reducing sugars (*mg/g*)	Starch (%)
Manitou	78.2	0.023	0.028	1.23	57.2
Stewart 63	81.0	0.034	0.238	1.87	56.6
Prolific	66.4	0.024	0.409	2.39	57.2
8A92	64.2	0.029	0.408	1.54	54.2
6531	65.0	0.041	0.762	2.01	55.3
6A250	59.6	0.020	0.084	2.32	57.1
6A320	59.6	0.031	0.292	1.90	51.5
64563	61.0	0.031	0.694	2.39	51.9
6517	57.8	0.033	1.673	3.33	54.0
6A190	54.4	0.039	2.001	3.59	51.9
6211.2	54.3	0.040	1.872	4.21	49.1

[a]Determined by the viscometric method of Tipples (1969).

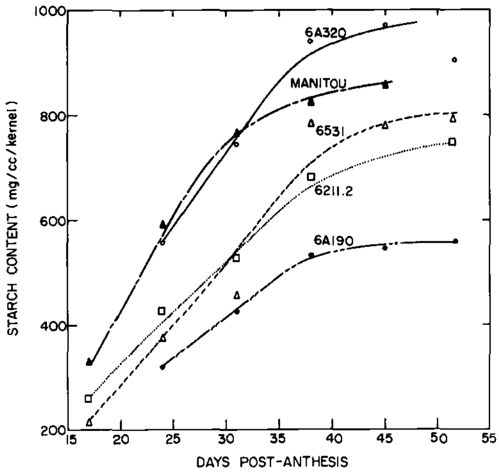

FIG. 1. Starch content in some triticale cultivars and Manitoba wheat as a function of kernel development.

unit of kernel volume of 6211.2 and 6A190 is lower than the varieties 6531 and 6A320. These latter two varieties have superior seed characteristics. Manitou starch content reaches a plateau level 5–10 days earlier than triticale. The results in Fig. 1 have been expressed on a seed volume basis to assess the ability of the particular variety to fill the available space in the endosperm. Thus, Manitou, a wheat variety that has relatively small seeds, does not deposit as much starch per seed as 6A190, a large-seeded triticale. However, when considered on a volume basis the synthesis of Manitou is sufficient to completely fill the volume within the endosperm whereas 6A190 is extremely shrivelled.

In addition to the reduced levels of starch deposition in shrivelled varieties, the rate of sucrose transport to the kernels may also be limiting. This is suggested by feeding experiments in which 16-day-old heads of 6A190 and 6531 were allowed to take up ^{14}C-labelled sucrose via the cut stems. The radioactivity incorporated into the endosperm and pericarp–testa was determined and the results are summarized in Table 2. Considering the total radioactivity incorporated, the cultivar 6A190 is 6% less efficient at transporting sucrose to the kernel when compared to 6531. In terms of sucrose incorporation into the endosperm, 6A190 transports 10% less sucrose than 6531. In addition, 6A190 directs a greater proportion of the incorporated radioactivity into the pericarp–testa than 6531. Thus, at the stage where endosperm starch synthesis is occurring most rapidly the shrivelled triticale cultivar is transporting sucrose at a slower rate and converting a greater proportion of the transported radioactivity into nonstorage materials in the pericarp–testa.

TABLE 2. Sucrose–^{14}C incorporation into grain of excised 16-day-old heads of two triticale lines.

	Incorporation (*dpm*)		
	6531	6A190	6A190 as % of 6531
Endosperm	26,989	24,481	90.7
Pericarp–testa	10,169	10,558	104.1
Total	37,158	35,039	94.3

As a follow-up to the earlier observations on a relationship between α-amylase activity and kernel shrivelling, we recently studied the localization of α-amylase in the tissue during the maturation period in four varieties of triticale. Two of the triticale varieties, 6A190 and Beaver 'S' (E_1-68B-5N), are shrivelled whereas the other two, 6A250 and Kangaroo × UM940, are plump. We included the Beaver and Kangaroo lines because they are advanced lines compared to 6A190 and 6A250, which are new amphiploids. The changes in the total α-amylase in these samples during development are shown in Fig. 2. All varieties have a characteristic peak of activity at about 12–15 days, which declines to a minimum at approximately 20 days. There is a second peak of enzyme activity at 28–32 days in all varieties, except 6A190, followed by a decline as the grain matures. The second burst of activity is unique in 6A190 since it continues to increase as the grain matures reaching levels characteristic of malted grains. The α-amylase activity in the shrivelled varieties is higher than that in the nonshrivelled varieties even though the difference is not pronounced in the Beaver line.

The localization of α-amylase activity in the tissue of 6A190 is shown in Fig. 3. The

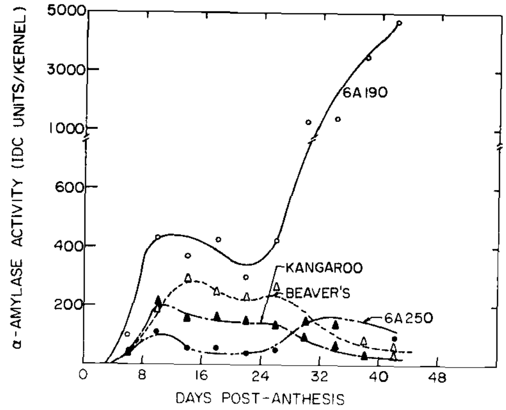

FIG. 2. Variation in total α-amylase of selected triticale lines at various stages of seed development.

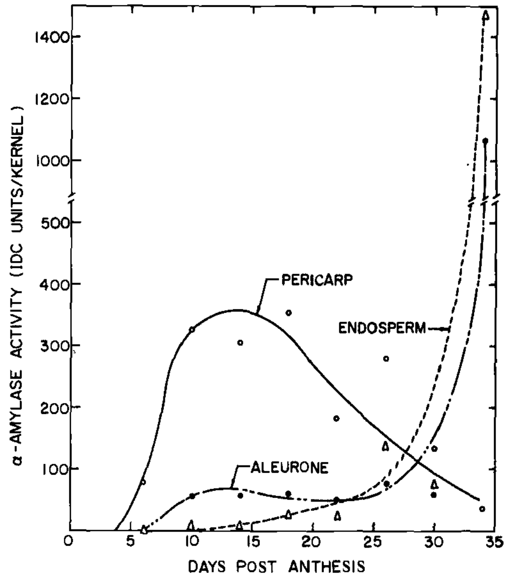

FIG. 3. Variation in the pericarp, endosperm, and aleurone α-amylase of triticale cultivar 6A190 at various stages of development.

peak of enzyme activity observed at approximately 12–15 days in the whole seed is associated almost entirely with the pericarp. This agrees with earlier work on the development of α-amylase in barley (MacGregor et al. 1972) and in wheat (Kruger 1972). This enzyme may degrade pericarp starch during early seed development providing nutrients for endosperm synthesis. As maturation proceeds, the pericarp amylase declines, and at approximately 22 days, the α-amylase activity within the aleurone and endosperm tissue of 6A190 increases dramatically. The development of α-amylase activity within the aleurone layer is normally associated with germination processes and may indicate the onset of precocious germination in this variety.

The development of α-amylase activity in the other three triticale lines is shown in Table 3. Pericarp α-amylase activity in all

TABLE 3. Distribution of α-amylase in triticale kernels during development.

Days after anthesis	Amylase activity[a]								
	6A250			Beaver 'S'			Kangaroo × UM 940 'S'		
	Pericarp	Aleurone	Endosperm	Pericarp	Aleurone	Endosperm	Pericarp	Aleurone	Endosperm
	(IDC *units/kernel*)								
6	24	5	0	36	15	3	27	19	3
10	66	12	6	130	38	8	148	34	12
14	36	5	7	240	26	15	138	19	6
18	61	10	0	216	39	8	142	43	13
22	22	11	5	223	27	20	143	8	19
26	37	10	7	256	46	20	74	38	30
30	20	14	10	70	50	50	82	21	7
34	4	27	8	58	31	40	34	20	13
38							18	10	6

[a]Determined by the McGregor et al. (1971) method.

lines is maximal during the period from 10 to 20 days. However, in the Beaver line this activity is higher and more prolonged than in the other two lines. Aleurone and endosperm activity is relatively low in all lines throughout the development period when compared to 6A190. Thus, the presence of amylase activity in association with shrivelling, although still evident in the pericarp tissue, is not as dominant in the Beaver line. The lack of a significant endosperm and aleurone α-amylase in the shrivelled Beaver 'S' line may indicate that shrivelling is not associated with precocious germination in this cultivar. Confirming this will require an analysis of events in the germination process that normally occur prior to the appearance of α-amylase.

In general, our results indicate that shrivelled cultivars of triticale have higher kernel α-amylase levels both at maturity and during their development than non-shrivelled lines. The rate of starch deposition in shrivelled cultivars relative to kernel volume is slower than in plump-seeded cultivars. Studies with 6A190 suggest that nutrient transport to the head may also be limiting in shrivelled cultivars.

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Improving Seed Formation in Triticales

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Abstract Inferior seed development resulting in shrivelling, poor germination, and low test weight is a major problem in triticales. The first signs of abnormal development appear during the latter stages of grain filling as flattened areas or depressions on the surface of the seed. As the seed matures, wrinkles appear on the seed coat, the crease deepens, and the endosperm texture becomes chalky rather than vitreous.

It appears that: (1) seed development in triticale is more sensitive to environmental influences than the parental species; (2) better seed development usually occurs among the most fertile strains; (3) the more shrivelled seeds are usually higher in protein content.

Some of the approaches used to overcome endosperm shrivelling are density gradient solutions, visual screening for plumper grain, mutagenic agents, selection for higher fertility, air column separation, and the gravity table. Because of the negative association between dwarfing and plump seed, visual screening tended to eliminate all the dwarf selections. The best results have been obtained from visual selection for plumpness in the most fertile populations. The gravity table will be useful in eliminating the very poor seed types in early generation material.

Résumé Le mauvais développement du grain, qui se traduit par son ratatinage, une mauvaise germination et un poids spécifique faible constitue une difficulté majeure en ce qui a trait aux triticales. Les premiers signes d'un développement anormal apparaissent au cours des derniers stades du remplissage du grain, sous forme de zones aplaties ou de dépressions sur la surface du grain. Au fur et à mesure que le grain mûrit, son tégument se ride, son pli s'approfondit et la texture de l'endosperme devient plus farineuse que vitreuse.

Il semble que: (1) chez le triticale, le développement du grain soit plus sensible aux influences du milieu que chez les espèces parentes; (2) c'est chez les souches les plus fertiles que le développement du grain est habituellement le meilleur; (3) les grains les plus ratatinés sont habituellement ceux dont la teneur en protéine est la plus élevée.

Quelques uns des moyens employés pour parer à ce problème des grains ratatinés sont: les solutions de sédimentation en gradient, le tri visuel des grains les plus pleins, la mutagénèse induite, la sélection en vue d'une fertilité plus élevée, la séparation pneumatique en colonne et le triage gravimétrique. Etant donné la relation négative entre le nanisme et le caractère grain plein, le tri visuel a été orienté vers l'élimination de toutes les variétés naines. C'est avec la sélection visuelle parmi les populations les plus fertiles que l'on a obtenu les meilleurs résultats sur le plan rondeur des grains. Le triage gravimétrique s'est révélé très utile pour éliminer les semences les moins bonnes dans les produits des premières générations.

A UNIVERSAL problem facing scientists working on triticale improvement is inferior seed formation. Seed development after fertilization superficially appears to progress normally during the early stages. As the spikes approach maturity, conspicuous abnormalities appear and become progressively worse as the seeds lose moisture. Usually, the first obvious signs of abnormal development appear as flattened areas or depressions on the endosperm, and the formation of a deep or evacuated crease. As the seed dries, wrinkles appear in the seed coat, lustre disappears, the sides become flattened, and the endosperm texture becomes floury or chalky rather than the hard, vitreous material found in the bread and durum wheats. The seed density is much lower. Dr L. Klepper (unpublished data 1970–71, CIMMYT) points out that the greatest difference in seed development between triticales and the parental species is the proportion of water present in the developing seed beginning shortly after fertilization and continuing until after the seed is physiologically mature.

The most pronounced abnormality in seed development occurs in the primary amphiploids. The octoploids generally have better seeds than the hexaploids. It is even worse in the polyhaploid hybrids to such an extent that embryo culturing is necessary to obtain the hybrid between *Triticum durum* × rye. There is a tendency toward improvement in seed development in the succeeding generations following the A_1 generation of the primary triticales but stops before satisfactory seed development is reached. Further improvement is obtained from secondary triticales, that is, from crosses among primary hexaploid, among primary octoploids, or among crosses between hexaploid and octoploids. The seed development among the early generations of these crosses, particularly from the F_1, is frequently more abnormal than among the parental forms. Improvement again occurs in the first few succeeding generations.

Observations on seed development show: (1) that seed development in triticales is more sensitive to environmental influence than the parental species; (2) that the better seed development occurs among the more fertile types but not necessarily among the most productive ones; and (3) that the more severely shrivelled types have higher protein content, and screening for better seed type and higher yield tends to favour lower protein content.

Dr V. D. Burrows (personal communication) from the Ottawa Research Station, Agriculture Canada, has done some preliminary investigations on seed formation. He found that seed coat shrivelling tends to mask endosperm development. There are forms that have a rather well-developed endosperm but have a wrinkled seed coat, whereas some types with poor endosperm development produce a flattened seed with less shrivelling of the seed coat. However, in general, a high degree of shrivelling indicates poor endosperm development. Burrows has developed a technique of removing the seed coat without destroying germination.

Several approaches have been attempted at CIMMYT to improve seed type:

The use of density gradient liquids for screening heavier seeds — This technique has not been satisfactory. Techniques and density gradient liquids available were too time-consuming and reduced germination.

Early attempts at *visual selection* for plump kernels tended very strongly to eliminate all the selections having dwarfing genes of Norin 10 origin.

Use of mutagenic agents — Dr Ake Gustaffson of Lund, Sweden, treated two strains of triticales from the CIMMYT program with both radiation and chemical mutagens. This material is now in its fifth generation following treatment. Improvement in seed type has not been encouraging, although mutations for characteristics other than seed type, mostly detrimental, were noticeable particularly in the second and third generations after treatment.

Selection for both fertility and seed type on a visual basis among secondary hexaploids derived from hexaploid × octoploid triticales and hexaploid triticales × bread wheat then backcrossed to hexaploid triticales — Visual selection in this material has been the most promising. At the end of the 1972–73 cycle at CIANO, about 15–20 selections had fairly plump grain and test weights of 74–76.5 kg/hl. This is still 8–10 kg/hl below the best bread wheat strains such as Inia.

Gravity table — This is equipment designed by Kipp Kelly, Winnipeg, to separate grains on the basis of density and size. The heavier, larger seeds move upwards on an inclined table, and the lighter, smaller seeds remain on the lower side. The machine requires at least 1 kilo of seed since the table must be covered to operate effectively. This system cannot be used to screen seed from single plants but can be used for bulked early generations. We expect that this type of seed-sorting equipment will be very useful with the bulked material from F_1 and F_2 generations. Material from more advanced generations will be screened on the basis of seed appearance from individual selections until a more effective technique is developed. Although this type of screening will discriminate against the dwarfs, we now have numerous populations having different combinations of dwarfing genes and it is unlikely we will lose complete populations.

Univalency in Triticale[1]

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KALTSIKES, P. J. 1974. Univalency in triticale, p. 159–167. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The ideas advanced to explain univalency in triticale are discussed under three headings: cytological (allocycly and precocious chromosome separation); genotypic (inbreeding depression, deleterious genes, genome ratio, and ploidy barrier); and cytoplasmic effects. Both the cytoplasm and the nucleus have an effect on chromosome pairing in triticale. Univalents most likely arise from: (*a*) interference with premeiotic DNA replication, which results in a reduced number of regions left unreplicated until zygotene; these regions are postulated to be necessary for chiasma formation; or (*b*) insufficient time for wheat or rye chromosomes to effect pairing.

Résumé Les théories avancées en vue d'expliquer la monovalence chez le triticale sont exposées sous trois rubriques: effets cytologiques (alloploïdie et séparation précoce des chromosomes); effets génotypiques (dépression endogamique, gènes récessifs, rapport génotypique, barrière ploïdique); effets cytoplasmiques. Le cytoplasme et le noyau ont tous deux un effet sur l'appariement des chromosomes chez le triticale. La monovalence provient le plus souvent: (*a*) d'une interférence avec la réplication préméiotique de l'ADN, qui se traduit par une diminution du nombre de régions restant sans réplication jusqu'au stade zygotène, l'existence de ces régions étant estimée nécessaire à la formation des chiasmas; ou alors (*b*) d'un manque de temps pour l'appariement des chromosomes chez le blé ou le seigle.

A large part of the breeding effort in triticale has been directed toward the improvement of its ability to set seed, i.e., fertility. Fertility and meiotic instability, evidenced as univalents in first metaphase, are statistically independent of one another (Hsam and Larter 1973*a*; Merker 1971, 1973*a*, *b*). It is possible, therefore, that some of the lines selected for good fertility are meiotically unstable. Meiotic instability usually results in the production of aneuploid plants, which, on account of their reduced vigour, may depress yield. In this sense then, meiotic abnormalities may still constitute a problem in the successful commercial exploitation of triticale. Furthermore, the phenomenon of univalency

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is interesting from the theoretical point of view since it is observed when the two parental genomes are brought together in a common nucleus.

Over the years, several theories have been advanced to explain univalency. For convenience of discussion they are grouped here under three headings: cytological theories, i.e. those based on observations on cells within the same genotype (allocycly and precocious chromosome separation); genotypic theories based on observations on different genotypes (inbreeding depression, deleterious genes, genome ratio, and ploidy barrier); and cytoplasmic effect theories.

It is the purpose of this paper to critically review these theories and to suggest experimental approaches toward a better understanding of univalency in triticale.

Cytological Theories

As indicated above, these theories are based on observations made within genotypes, although comparisons among genotypes have also helped in their formulation.

Allocycly or Genomic Disharmony

Under this broad heading come several observations mainly concerned with the inability of the two parental genomes (wheat and rye) to coordinate their activities and work in unison within the common nucleus. Evidence for this inability was first noticed as differences in the rate and rhythm of chromosome contraction (Florell 1936; Stutz 1962). Later, Shkutina and Khvostova (1971) obtained further evidence of genomic disharmony with respect to nucleolar formation in meiotic prophase. They found that there were two kinds of triticale: those having two or those having one nucleolus. Measurements of the weight of these nucleoli and observation of the number and kind of chromosomes associated with them, indicated that when two nucleoli were present the rye genome organized its own nucleolus separately. When only one nucleolus was present, three wheat chromosome pairs were associated with it, indicating inactivation of the rye genome. However, there were cases where both wheat and rye chromosomes participated in the formation of one nucleolus. Shkutina and Khrostova (1971) interpreted their observations with respect to univalency in triticale as follows: in those triticale where the rye genome, as evidenced by its lack of participation in nucleolar formation, is inactive, it does not form a spindle, thus resulting in a random distribution of rye chromosomes (i.e., univalents), or even their lysis by the cytoplasm. When in these triticale the rye genome does form a spindle, it is separate from that of wheat and results in polyad formation. In those triticale that form nucleoli in which both rye and wheat chromosomes participate in nucleolar formation, unspecified "physiological disturbances" occur that interfere with normal spindle organization resulting in multipolar divisions, univalents, and eventually aneuploids.

Appealing as these observations are, they still do not represent a one to one relationship between nucleolar formation and meiotic abnormalities. Furthermore, if they are taken at face value, they would imply that all univalents are from the rye genome, which is not always the case (Larter and Shigenaga 1971; Shigenaga et al. 1971). Additionally, at present no relationship seems to exist between nucleolar and spindle formation. The lack of spindle formation, on the part of the rye genome, was not observed but was rather inferred from the distribution of the rye chromosomes. Polarizing microscopy could be used to determine the existence of differences in spindle formation.

The present author has failed to observe the phenomena reported by Shkutina and Khvostova (1971) and Stutz (1962) in sufficient quantity to explain the meiotic disturbances observed in triticale.

However, even if the differences between the rye and wheat chromosomes in proceeding through meiosis are such that they cannot always be visualized, it still remains as a possibility that during meiosis the time available to rye chromosomes for pairing and chiasma formation is not sufficiently long.

Indirect evidence for this comes from the combination of two observations: one, that on average, octoploid triticales have more univalents per cell (mostly belonging to the rye genome) than hexaploid ones; and two, that meiotic duration in hexaploid triticale (37 h) is more compatible with that of rye (51 h) as opposed to the very short duration of meiosis (20 h) in octoploid triticale (Bennett and Kaltsikes 1973). It is possible then that in hexaploid triticale rye chromosomes have sufficient time in which to pair and form chiasmata, thus resulting in fewer univalents per cell (see also later). If this were true, a hexaploid triticale with meiotic time requirements closer to those of rye should be quite stable meiotically. This would require a tetraploid wheat with a different amount of DNA from those utilized to date for triticale production. However, there does not seem to be much variation in DNA content at the tetraploid wheat level (Bennett 1972); because within a ploid level the duration of meiosis and amount of DNA are positively correlated (Bennett 1971), a suitable tetraploid wheat parent with meiotic duration characteristics similar to those of rye may not exist. There remains of course the rye parent; the species of the genus *Secale* L. are quite closely related and, although no DNA values have been reported for the whole genus, it is possible that there is not much variation in *Secale* either. The chromosomes of rye are, on the average, larger than those of wheat and carry almost 1.5 times the amount of DNA and associated proteins in comparison with those of tetraploid wheat. If these differences in size and mass, as it seems likely, determine different rates of meiotic development, then univalency will probably remain a problem in triticale development. However, there might be ways of overcoming the problem imposed by the large amount of DNA carried by the rye genome. For example, in flax (Durrant 1962) by varying the fertilizers supplied to the variety Stormont Cirrus, genotypes differing in the amount of nuclear DNA have been produced (Evans 1968). Recently Cullis (1973) has shown that the genotype carrying less DNA has a higher percentage of unique DNA sequences relative to the genotype, which has more DNA. This possibly means that there is a mechanism whereby some of the repeated sequences of DNA present in rye could be excised prior to its incorporation in triticale without loss of information. In this way the requirements for pairing of rye chromosomes might become more comparable to those of wheat. Alternatively, the amount of DNA in wheat could be increased by some suitable treatment to make it more compatible with that of rye with respect to duration of meiosis.

The incidence of allocycly reported by several authors may be taken to mean that the two genomes are possibly replicating their DNA at different times. However, no proof of this exists as of yet. Although most rye chromosomes can be identified as such in triticale, the best material for a study of this nature would be 7x or 5x hybrids in which the rye genome will be entirely made up of univalents. Additionally, rye addition lines might also be utilized. Tritiated thymidine can be fed into the sporocytes an dits incorporation by the replicating chromosomes can be ascertained. If the two genomes replicate at different times it should be easy to differentiate the early from the late replicating genome. Alternatively, replication can be studied in mitosis following short pulses of tritiated thymidine and collection of metaphases at different times following the pulse. If whole chromosomes or even genomes replicate autonomously they should be quite easy to observe.

Precocious Separation of Bivalents

Reduction in chromosome pairing has been observed from metaphase to telophase in both divisions in octoploid and hexaploid triticale (Shkutina and Khvostova 1971) and from diakinesis to MI at the hexaploid level (Tsuchiya 1970). Thomas and Kaltsikes (1972) observed a reduction in the number per cell of paired chromosome ends (chiasmata) in the last cells of an anther to finish metaphase I. The reduction in pairing observed was attributed by Tsuchiya (1970) to terminalization and failure of chiasmata after diakinesis. The reduction, however, could be more apparent than real as he himself commented that some of the pairing at diakinesis might have been achiasmate. These associations would separate during metakinesis prior to the formation of a clear metaphase plate (Thomas and Kaltsikes 1972). Shkutina and Khvostova (1971) were led to the belief of premature separation by the observation that univalents of similar size and shape were found across from one another on opposite sides of the metaphase plate. However, when Thomas and Kaltsikes (1972) studied the distribution of such chromosomes in cells with only two univalents, which were easy to identify, they found no evidence of such relict coorientation. More work is needed in this area before this question can be settled. An experimental approach to this problem will be discussed elsewhere.

Genotypic Theories

The ideas incorporated in these theories were obtained from observations among different genotypes.

Inbreeding Depression

Secale cereale is normally an outbreeding species. Upon inclusion in triticale it is forced to inbreed and this according to Muntzing (1957) may be the cause of univalency since it is known that inbred lines of rye show various meiotic abnormalities and reduced chiasma formation. However, if this were true: (*a*) triticale produced with either inbred lines or naturally self-fertilizing species of rye should have better meiosis; and (*b*) the F_1 between two triticale should have a stable meiosis since heterozygosity with respect to rye genome would be restored. This has not been the case. Thus, the utilization of inbred rye lines in the production of triticale has not resulted in improvement of their meiosis (Cauderon, personal communication). Additionally, a triticale made by utilizing *S. vavilovii*, a naturally self-fertilizing species, was in effect worse than those made utilizing *S. cereale* (Krolow 1966). Furthermore, the meiosis of the F_1 between two octoploid triticale lines (Bjurman 1958) and several hexaploid lines (Merker 1973*a*) was not better than either one of the parents. However, the case here is not as strong since intervarietal hybrids of many species show more univalents than their parents (Hollingshead 1932; Thompson and Robertson 1930). Furthermore, amphiploids between *T. aestivum* and *Ae. longissima*, both self-fertilizing species, were not better meiotically than triticale (Riley and Chapman 1957).

James MacKey (personal communication) thinks that amphiploids that self-fertilize can only have one outbreeding species in their genomic make up (*Aegilops speltoides* in the case of wheat). According to him the addition of another outbreeder, rye, to form triticale, changes the balance and results in abnormalities. Apart from the fact that there are serious objections to the idea that *Ae. speltoides* may have contributed the entire B genome (Kimber and Larsen 1973), the addition of the inbreeder *Secale vavilovii*, as noted above, did not improve the meiotic stability of the resulting triticale.

Deleterious Genes

Krolow (1966) thought that the meiotic abnormalities in octoploid triticale might be due to genes residing on D genome chromosomes that influence the rate of chiasma formation on rye chromosomes. Pieritz (1966) on the other hand thought that genes on rye chromosomes might be affecting chiasma formation. Both were led to this belief from observations that indicated that the octoploid triticale were meiotically more stable than hexaploid triticale. Confirmatory evidence on this comes also from the observations of Kiss (1966) that secondary triticales are more stable than primary ones. There is, however, conflicting evidence on this. Thus, Sanchez-Monge (1958) did not find any difference between the two levels of ploidy. The results of Shkutina and Khvostova (1971), who also did not find any differences, merit closer attention. If one were to take the frequency of aneuploidy reported by them at face value then hexaploid triticale is a lot better with an aneuploidy rate of 27.11% as opposed to 45.17% for the octoploid triticale. However, these values were arrived at by examination of PMC's at MI. Other workers have reported PMC's with drastically reduced chromosome numbers (Muntzing 1957; Muntzing et al. 1963; Kappus 1964). It is conceivable that broken cells were scored as whole since Shkutina and Khvostova (1971) found the mitotic irregularities for the two groups referred to above to be quite small (9.20% for the hexaploid triticale and 7.45% for the octoploid). Since PMC's are derived from mitotic divisions one cannot see why there should be such a difference in the two processes. Furthermore, if the hexaploid triticale indeed have fewer univalents in MI, then scoring abnormal tetrads instead of microsporocytes with micronuclei will tend to favor octoploid triticale, which would normally have more micronuclei per tetrad but not necessarily per sporocyte. This contradicting evidence may mean that there is some gene or genes that control pairing, the effect of which may vary depending on the particular combination of the genotypes involved in the production of the amphiploid. These genes may not necessarily reside on the D genome chromosomes. If this were the case then there would be a common cause for univalency at both ploidy levels, in which case a mechanism to account for it must be sought. Pieritz (1966) has reported the existence of a triticale line that is remarkably stable with respect to its meiosis. If this line were to be crossed to a line with a large amount of meiotic abnormalities, then, in the products of segregation, lines could be found with meiotic stability equal to that of the better parent, provided of course that the genetic system is relatively simple. A cross of this nature would provide evidence for or against genes responsible for meiotic abnormalities. Evidence that such genes exist comes from several sources. Shigenaga and Larter (unpublished) found that Rosner monosomic for 1B had fewer univalents per cell than other monosomics meaning that 1B carries genes that influence the pairing of other chromosomes. Riley et al. (1973) have shown that a rye chromosome arm influences the pairing of wheat chromosomes when added to wheat. Similar results were obtained by Muntzing et al. (1963) and O'Mara (1947). Additionally, Riley and Miller (1970) at the octoploid level and Thomas and Kaltsikes (1971) at the hexaploid level have shown that the 5B system of wheat may interfere with normal pairing of rye chromosomes. Genetic influences on chiasma frequencies have been reported in other species as in *Antirrhinum* (Ernst 1938), *Dactylis glomerata* and *Lolium perenne* (Meyers 1941, 1943), and *Triticum aestivum* (Berg 1935; Love 1951; Riley and Law 1965). Interaction between wheat and rye chromosomes may also contribute to meiotic abnormalities in triticale.

Genome Ratio

Muntzing (1957) suggested that meiotic irregularities might be related to the ratio of rye to wheat genomes in the amphiploid. He based his suggestion on observations on triticale of the hexaploid, octoploid, and decaploid levels, which indicated that as the ratio of wheat to rye genomes moved from 2:1 to 3:1 and 3:2 irregularities increased. Bennett and Kaltsikes (1973) think that the ratio of genomes is a manifestation of different amounts of DNA content, which, in turn, affect meiotic duration as a whole and, in particular, those phases of meiosis (zygotene and pachytene) related to pairing and chiasma formation. Thus, the addition of one rye genome to two wheat genomes (hexaploid triticale) reduces the rate of meiotic development and causes zygotene and pachytene to occupy approximately 40% of the total duration of meiosis. In contrast by the addition of one rye genome to three genomes of wheat (octoploid triticale) the rate of meiotic development is increased and zygotene and pachytene take up only 25% of the total duration of meiosis. If one takes into account the fact that in diploid rye, zygotene and pachytene take up 38% of this time, one is led to the conclusion that the "time limit for pairing" theory of Darlington (1940) might be valid here. According to this theory there is a positive correlation between duration of pairing and amount of pairing. The observations reported by Bennett and Kaltsikes (1973) suggest that in hexaploid triticale the rye chromosomes pair more than in the octoploid ones because they are allowed more time to do so.

One of the tetraploid triticale types produced by K. D. Krolow is quite stable meiotically. It would be interesting when the complete series of triticale becomes available, i.e., 4x, 6x, 8x, to compare them under identical conditions. The best approach to the problem would be to extract the AABB component from a readily crossable hexaploid wheat and utilize it to transfer one of the crossability genes to *T. monococcum.* Once this is accomplished, then the whole series can be produced utilizing the same genotypes with a variety of rye genotypes to test the influence of the ratio of the genomes on the occurrence of univalents in triticale.

Polyploidy or Valence Barrier

This idea was proposed by Pieritz (1966) to explain the differences in univalency between octoploid and hexaploid triticale. Accordingly, the maximum chromosome number would be just over 42 and everything above it would be very irregular. The higher the chromosome number the more irregular the meiosis and the more pronounced the tendency to bring it down to the 42 chromosome level. Sanchez-Monge (1958) felt that the 56 chromosome number was too high and that the 42 chromosome level would be preferable. However, he could not find proof for his intuition as hexaploid triticale involving *T. dicoccum, T. dicoccoides,* and *T. durum* were more abnormal than octoploid ones. However, Pieritz (1966) and Krolow (1966) provide proof to the opposite. The present author does not really comprehend the reasoning behind the valence barrier. It is included here for reasons of completeness only.

Cytoplasmic Effects Theories

It is only recently that the effect of the cytoplasm upon meiotic behaviour has been studied. Thus, Larter and Hsam (1973), following a proposal by Sisodia and McGinnis (1970), made reciprocal crosses between tetraploid and hexaploid wheat and utilized the resulting hybrids to produce triticale that were identical in all other respects but the origin of the cytoplasm. From eight such combinations they found that six having hexaploid wheat cytoplasm had significantly fewer univalents per cell relative to those having tetraploid wheat cytoplasm, whereas the other two had fewer univalents but not significantly so. In light of these results, the finding of Thomas and Kaltsikes (1972), that triticale (the wheat parent of which was the extraited AABB component of hexaploid wheat) had a more regular meiosis than durum × rye triticale, may have been due to the influence of the cytoplasm. Brandes et al. (1973) studied the influences of the wheat and rye cytoplasm on triticale and wheat–rye addition lines. They found that the cytoplasm exerted an effect either by itself or through the interaction with particular chromosomes. It is possible that the cytoplasm affects the duration of meiosis and especially those stages connected with pairing.

The state of the cytoplasm and the plastids have also been implicated as influencing chiasma formation by affecting "the physiological balance" of the plant (Pieritz 1966). Electron microscope studies of the different cytoplasms may shed light on their differential influence upon meiosis.

Discussion

From the foregoing it is apparent that no clear understanding exists of the causes and mechanism of univalency in triticale.

An important event, such as regular chromosome pairing, recombination, and division, must be under genetic control. No doubt the genetics of this control system are complex and it has taken time to evolve for each species. When two established species are brought together to form a hybrid or an amphiploid either a new hybrid control system with regard to division has to be established or the system of one or the other parent will take over. Evidence from the duration of the meiotic cycle (Bennett and Kaltsikes 1973) indicates that a new hybrid system is formed in triticale. This system is responsive to genetic selection both natural and artificial as evidenced by the efficiency of selection for meiotic stability in triticale lines obtained from breeding programs (Hsam and Larter 1973*b*).

When a new hybrid or amphiploid is formed, the duration of the cycle is long but it becomes shorter after selection for meiotic stability. Thus, for a raw amphiploid (6A190) that has never been subjected to artificial selection for meiotic stability, the duration of the meiotic cycle was 37 h (Bennett and Kaltsikes 1973), whereas for Rosner, an advanced triticale line, the duration was 34 h (Bennett and Smith 1972). The shortening of the cycle in Rosner was entirely due to the shortening of the period from the beginning of meiosis to first metaphase. If the period from the beginning of meiosis to the end of pachytene is viewed as a modified G_2 period (Swanson et al. 1967), i.e., a period preparatory to chromosome separation, then it can be argued that the time required for the manufacturing and assembly of the proteins and spindle components necessary for division is longer in raw unselected amphiploids than in established lines. A similar situation exists with respect to mitosis (Kaltsikes 1971, 1972) in triticale and in somatic cell hybrids of animal species (Marshall Graves 1972). Marshall Graves (1972) thinks that there was probably initially incompatibility of factors required for division that is later removed by the correction of some initial defect, or by loss of one parental set of factors through karyotypic change or genetic alteration or through the evolution of a hybrid control system.

Whatever the causes of univalency in triticale, their effect must be brought about by (*a*) prevention of chromosome pairing; (*b*) prevention of chiasma formation; or (*c*) precocious separation of chromosomes that have already paired and formed chiasmata. Chromosomes can be prevented from pairing by interference with their premeiotic prealignment or later by interference with the formation of the synaptinemal complex that is necessary for, but does not necessarily lead to, chiasma formation.

Chiasma formation can be prevented a long time prior to zygotene by interfering with premeiotic DNA synthesis. Chiu and Hastings (1973), working with *Chlamydomonas reinhardi*, have hypothesized that the amount of recombination (i.e., effective chiasma formation) is directly proportional to the number of regions in the chromosomes in which DNA replication was delayed from the premeiotic S period to zygotene. If for any reason not enough sites on the chromosome are left unreplicated at the end of premeiotic S, then, although the chromosomes (due to the formation of the synaptinemal complex) are closely aligned, little or no chiasma formation will take place. The observations indicating complete chromosome pairing at pachytene but lack of chiasma formation (Thomas and Kaltsikes, unpublished data) could be explained on this hypothesis. Precocious separation of already effectively paired chromosomes could result from premature spindle action.

Although we can offer no cohesive testable theory for univalency in triticale, there are ways of discriminating between univalents due to lack of chiasma formation and those due to premature disjunction as a result of early spindle action. Thomas and Kaltsikes (in preparation) offer several experimental approaches to the problem.

Acknowledgments

Financial assistance from the Canadian International Development Agency and the International Development Research Centre is gratefully acknowledged.

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Cytogenetics of Hexaploid Triticale

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MERKER, ARNULF. 1974. Cytogenetics of hexaploid triticale, p. 169–172. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Results obtained from studies in Lund, Sweden, and on the cytogenetic research being carried out at El Batan at the present time are reported on. Meiotic disturbances, which give rise to aneuploid plants, do not seem to have any direct influence on fertility. As well, recent results from karyotype analysis of aneuploids in hexaploid triticale contradict the view that meiotic disturbances in triticale are limited to the rye genome.

A new more rapid and precise method of chromosome identification is also discussed.

Résumé L'auteur rend compte des résultats des travaux effectués à Lund, en Suède, et des recherches en cytogénétique actuellement en cours à El Batan. Les perturbations méiotiques, qui se traduisent par l'apparition de plants aneuploïdes, ne semblent pas avoir une influence directe sur la fertilité. De plus, les résultats d'analyses récentes de caryotypes d'aneuploïdes chez des triticales hexaploïdes contredisent l'opinion selon laquelle les perturbations méiotiques sont limitées au génome seigle chez le triticale.

L'auteur expose également une nouvelle méthode plus rapide et plus précise d'identification des chromosomes.

IT was established already in the early 1930's that amphidiploids between wheat and rye suffer from cytological disturbances. During the last 10–15 years a great deal of information on the cytogenetics of hexaploid triticale has been accumulated.

This paper contains some results obtained from studies in Lund, Sweden, and on the cytogenetic research being carried out at El Batan at the present time.

All investigated lines of triticale have disturbances in the meiotic divisions as seen in studies on microspores. The most common disturbances are univalents at first metaphase, laggards at anaphase, and micronuclei in dyads and tetrads. There are statistically significant differences in frequency of disturbances between different lines. Between plants within lines the frequencies of disturbances are quite constant as long as the environment is kept constant (Merker 1971).

It was thought for a long time that the reduced fertility in triticale was a direct result of the meiotic disturbances. These disturbances do not seem however, to have direct influence on fertility, since lines with high frequencies of disturbances may have a good fertility has been established even though they have a poor fertility. This is illustrated in Fig. 1 and 2, which represent two F_2 populations

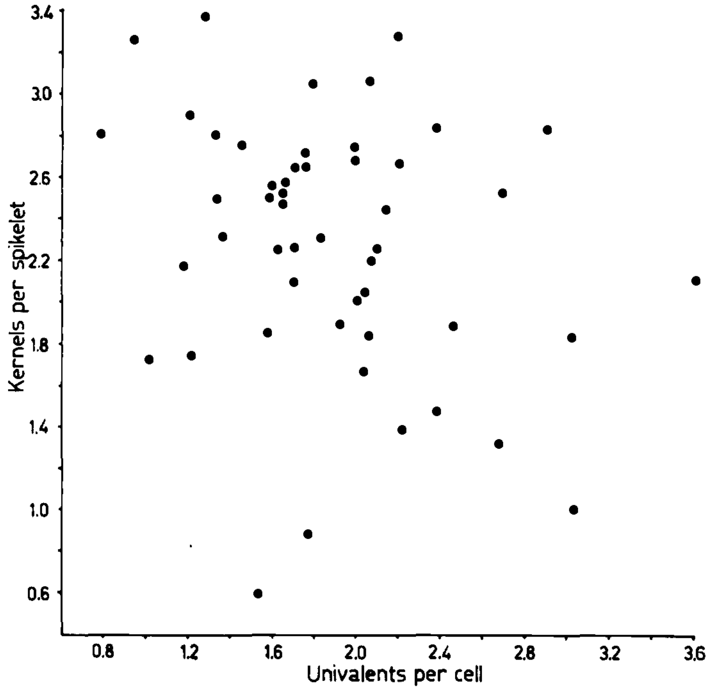

FIG. 1. Correlation between univalents per cell and kernels per spikelet in the F_2 population of the cross 6 × 125. $r = -0.26$ ($0.10 > P > 0.05$).

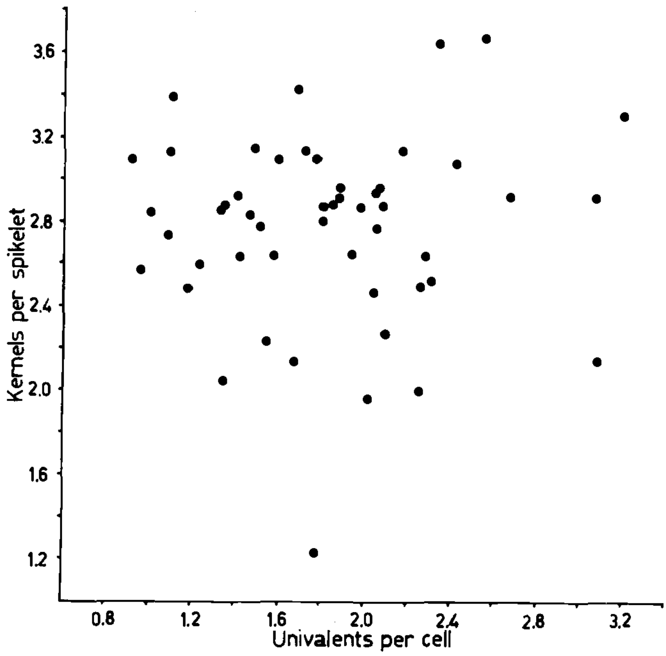

FIG. 2. Correlation between univalents per cell and kernels per spikelet in the F_2 population of the cross Rosner × 110. $r = -0.04$ ($P > 0.25$).

of crosses between lines with different frequencies of disturbances and different levels of fertility. The populations show a wide variation in both parameters. It is quite obvious that there is no significant correlation between disturbances and fertility (Merker 1973*a*). Therefore, the reduced fertility in triticale is mainly of a genic nature. In the Armadillo lines, a genetic system for high fertility has been established even though they are not without cytological disturbances.

The negative effect of the meiotic disturbances is that they give rise to aneuploid plants. These plants are less fertile and vigorous than euploids and reduce the yield potential of the lines. Therefore, minimizing the cytological disturbances should be a goal in triticale breeding.

It has been thought that meiotic disturbances in triticale are limited mainly to the rye genome. Recent results from karyotype analysis of aneuploids in hexaploid triticale contradict this view.

As aneuploidy is a result of pairing failure, lagging, or nondisjunction in meiosis, the identity of aneuploids gives a picture of meiotic disturbances. By means of karyotype analysis it is possible to distinguish between rye and wheat chromosomes in triticale (Merker 1973*b*). The rye chromosomes are the largest of the complement. Such analysis of aneuploids shows that aneuploidy is randomly distributed between the genomes of triticale, i.e., one-third rye chromosomes and two-thirds wheat chromosomes (Table 1). This shows that there is a general pairing

TABLE 1. Distribution of aneuploids between rye and wheat genomes in progenies of euploid plants in triticale line 110.

	Rye	Wheat	No. plants
Monosomic	16	23	39
Trisomic	4	11	15
Total	20	34	54

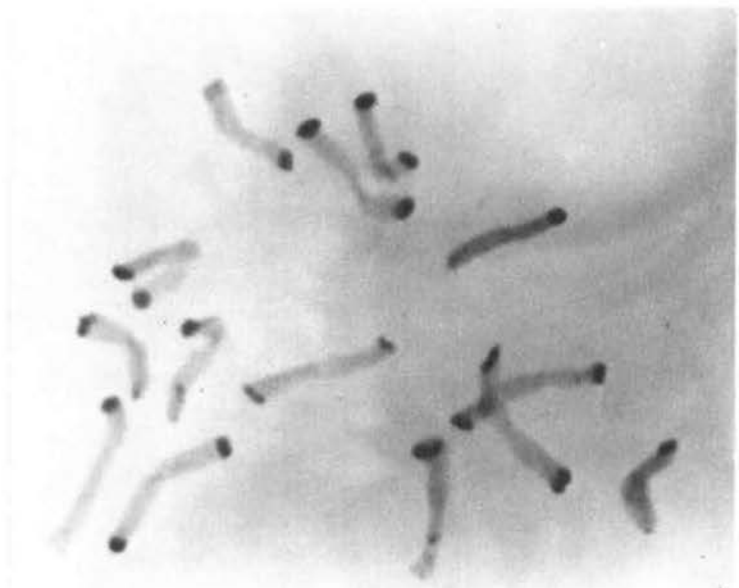

FIG. 3. Rye chromosome complement stained with Giemsa solution. Blocks of telomeric heterochromatin clearly visible.

Fig. 4. Triticale chromosome complement stained with Giemsa solution. Rye chromosomes identifiable by means of telomeric heterochromatin.

failure, which probably is a result of an imperfect genetic control system of meiotic chromosome pairing.

A new more rapid and precise method of chromosome identification has been made available by the new Giemsa banding techniques (Merker 1973*c*). When stained with Giemsa solution after a special pretreatment, rye chromosomes show heavily stained blocks of telomeric heterochromatin (Fig. 3). Wheat chromosomes show centromeric heterochromatin, intercalary bands, or no differential staining. This makes it possible to identify the rye and wheat chromosomes of triticale directly under the microscope without taking photographs, karyotype measurements, etc. (Fig. 4).

With this method, we are investigating triticale lines in the CIMMYT breeding program to obtain an idea of their chromosome constitution. It makes it possible to check if all seven pairs of rye chromosomes are present in the lines or if some of them are substituted by chromosomes from other genomes.

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Use of Chromosome Analysis to Detect Favourable Combinations from Octoploid × Hexaploid Crosses

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DE SOSA, M. H. 1974. Use of chromosome analysis to detect favourable combinations from octoploid × hexaploid crosses, p. 173–180. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract In 1973, an octoploid triticale line (FW 121 × Prolific rye) from the University of Manitoba was crossed with a hexaploid triticale (Cinnamon) from CIMMYT and a chromosome analysis was made on both parents as well as their offspring from F_1 to F_4. Results showed that the octoploid line had one of the lowest percentages of aneuploidy so far reported; that in spite of a high frequency of univalents, the hexaploid triticale showed a high fertility; and that the high yield in F_1 plants, the rapid decrease of the univalents number in F_2 to F_4 generations as well as the clear tendency toward the hexaploid level, could have been the result of the continuous search for plants with phenotypes resembling those of hexaploid lines.

Résumé Un triticale octoploïde (FW 121 × seigle Prolific), de l'Université du Manitoba, a été croisé en 1973 avec un triticale hexaploïde (Cinnamon) du CIMMYT, et l'on a procédé ensuite à une analyse chromosomique des deux parents et des générations F_1 à F_4. Les résultats ont démontré: que la lignée octoploïde avait l'un des pourcentages d'aneuploïdée les plus faibles que l'on ait signalé jusqu'ici; qu'en dépit d'une fréquence élevée en monovalents, les triticales hexaploïdes faisaient preuve d'une grande fertilité; que le rendement élevé des plants F_1, la diminution rapide du nombre de monovalents dans les générations F_2 à F_4 et la tendance très nette vers l'hexaploïdie, pourraient bien être le résultat de la quête permanente de plants dotés de phénotypes ressemblant à ceux des lignées hexaploïdes.

ALMOST 10 years ago, the University of Manitoba and CIMMYT established a cooperative program in triticale. During the summer of 1972, cytological studies in some triticale lines were started in CIMMYT laboratories. Besides the routine work, such as the identification of the chromosome complement and determination of the frequency of aneuploids in some octoploid and hexaploid lines, in February of 1973 we decided to make a chromosome analysis in offspring derived from crosses between octoploid and hexaploid triticale, in the hope that cytological studies will help plant breeders in the selection of lines with a high chromosomic stability.

An octoploid triticale line (FW 121 × Prolific rye) from the University of Manitoba was crossed with a hexaploid triticale

(Cinnamon) from CIMMYT and both parents as well as their offspring from F_1 to F_4 were analyzed.

Mitosis

The results of mitotic analysis are shown in Table 1. Plants derived from the octoploid triticale line showed 84.8% euploidy, 13.6% hipoploidy, and 1.51% hyperploidy. The frequency on euploid plants from this octoploid parent was higher than the frequency given to other lines by different authors.

The hexaploid line (Cinnamon) produced 90% euploid plants, 6% hipoploid plants, and 4% hyperploid plants. The chromosome number in F_1 plants ranged from 45 to 50. However, 66.7% of the population showed 49 chromosomes. As seen in Table 1, plants belonging to F_2, F_3, and F_4 generations showed a clear tendency to the hexaploid level.

Meiosis

Meiotic observations were made in randomly sampled plants. The octoploid parent generally showed 28_{II} during diakinesis (Fig. 1). However, the frequency of univalents per cell in metaphase-I ranged from 1 to 4 with a mean value of 1.5.

The hexaploid parent showed an acceptable chromosome pairing during metaphase-I (M-I) (Fig. 2) as well as a normal chromosome separation during anaphase-I (A-I) (Fig. 3). The mean frequency of univalents per cell was not higher than 1.1 (Table 2). At first glance, and even without statistical analysis, it is clear from the results shown in Table 2 that there is considerable difference among the mean univalent values in F_1 to F_4.

In F_1 plants, some meiotic disturbances, such as the formation of a higher number of univalents than expected, were found (Fig. 4 and 5). Laggards (Fig. 6) and micronuclei were not uncommon. In F_2, the chromosome

FIG. 1. Diakinesis in 8x line showing 28_{II}. 800×.

TABLE 1. Variation in somatic chromosome number in octoploid and hexaploid triticale and in their F_1, F_2, F_3, and F_4 offspring.

Material	Germination ability (%)	No. analyzed plants	Frequency (%) of plants with the following no. chromosomes: 40	41	42	43	44	45	46	47	48	49	50	51	54	55	56	57
8x from U of M	85	66											1.52	3.03	6.06	3.03	84.84	1.52
6x Cinnamon	92	50		6.0	90.0	4.0												
F_1 plants	80	78						2.56	5.13	6.41	16.67	66.67	2.56					
F_2 plants	82	49	6.12	6.12	49.00	10.20	10.20	4.08	6.12	4.08			4.08					
F_3 plants	74	72	1.39	20.83	68.05	2.78	4.17	1.39	1.39									
F_4 plants	70	47		8.51	80.85	6.38	2.13	2.13										

TABLE 2. Univalents at metaphase-I in octoploid and hexaploid triticale and in their F_1, F_2, F_3, and F_4 offspring.

Material	No. analyzed plants	No. PMC	Univalents: 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	18	$\bar{x}$
8x Tcl. (from U of M)	2	167		108	46		13												1.5
6x Tcl. (Cinnamon)	2	118	64		41		13												1.1
F_1 plants	6	360				1	55	64	57	91	23	44	11	8	1	4	2	1	7.1
F_2 plants	2	478			108		110		108		102		50						5.4
F_3 plants	2	244	175		51		18		1										0.71
F_4 plants	2	280	251		22	2	7												0.25

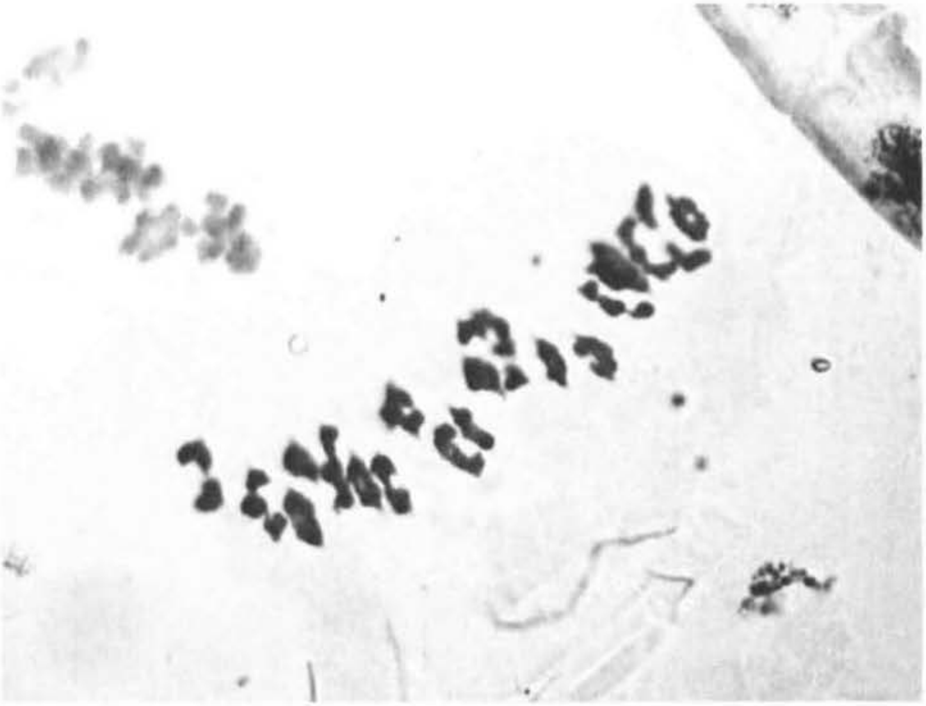

FIG. 2. Metaphase-I in 6x parent showing 21_{II}. 500×.

FIG. 3. Anaphase-I in 6x parent showing 21 chromosomes in each pole. 800×.

complement was not the same for the two analyzed plants. The first one was shown to have a chromosome complement of 45. However, the chromosome formula in the next two PMC were not the same, even though they belonged to the same author (Fig. 7 and 8). The second plant had 42 chromosomes with a normal separation during A-I (Fig. 9). Generally speaking, the chromosome behaviour in F_3 and in F_4 plants was normal.

Fertility

Fertility was measured by the number of seeds per spikelet (Table 3). The F_1 values for the number of seeds per spikelet and the number of spikelets per spike was less than between parents' values. In further generations, that is to say from F_2 to F_4, the values for these two characters did not show any consistent tendency to an increase or decrease. However, it was really unusual to have found a 2.25 seed per spikelet value in F_1 plants.

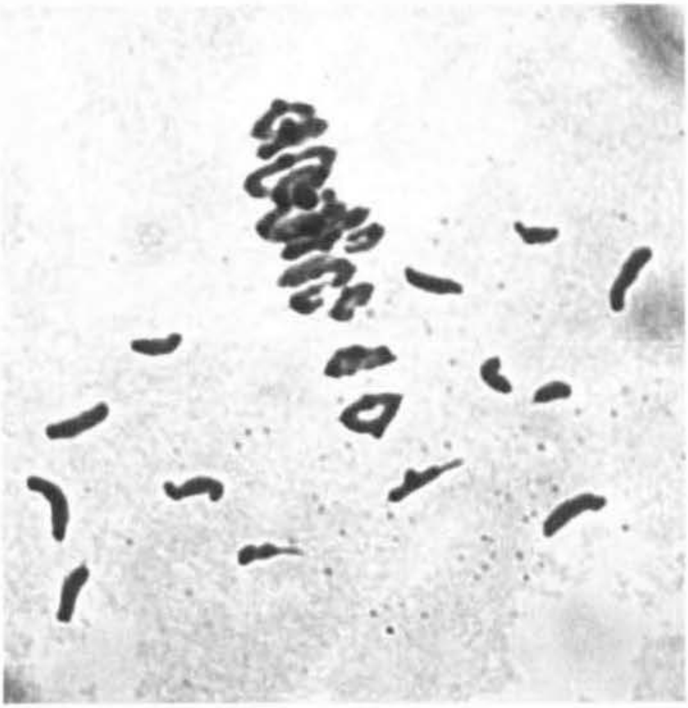

FIG. 4. Metaphase-I in F_1 plant showing at least 13_I. 800×.

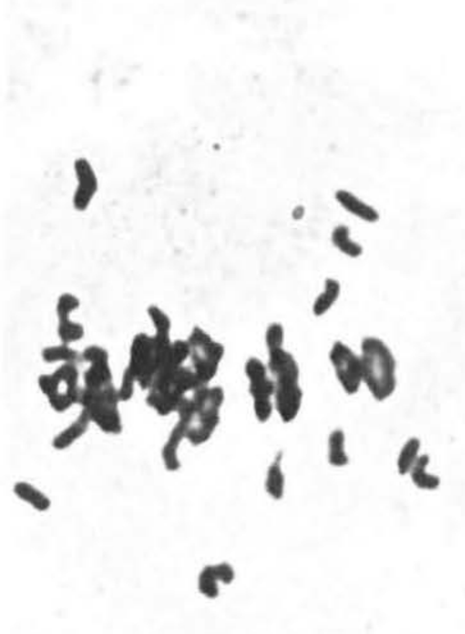

FIG. 5. Metaphase-I in F_1 plant showing 10 univalents out of the plate. 500×.

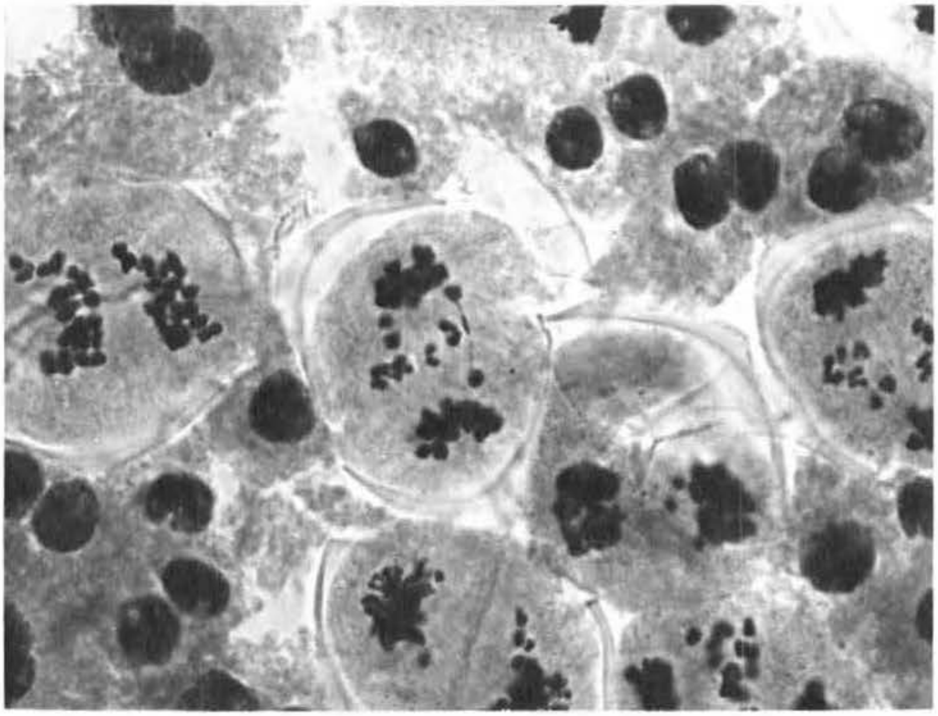

FIG. 6. Telophase-I in F_1 plant showing some laggards. 500×.

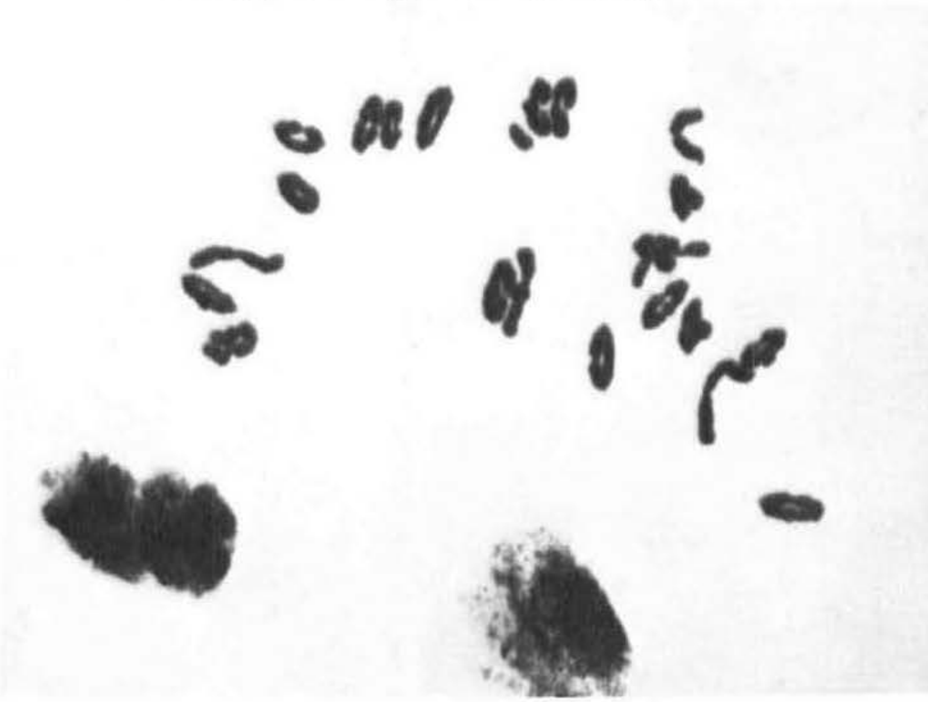

FIG. 7. Metaphase-I in F_2 plant showing $22_{II} + 1_I$. 800×.

FIG. 8. Metaphase-I in the same F_2 plant showing $21_{II} + 3_I$. 800×.

FIG. 9. F_2 plant with $2n=42$ showed an Anaphase-I with 21 chromosomes in each pole. 800×.

TABLE 3. Fertility and number of spikelets in octoploid and hexaploid triticale and in their F_1, F_2, F_3, and F_4 offspring.

Material	8x Tcl. (from U of M)	6x Tcl. (Cinnamon)	Plants F_1	F_2	F_3	F_4
Spikelets/spike	22.7	17.8	18.9	21.7	20.0	20.0
Seeds/spikelet	1.88	2.78	2.25	1.81	2.25	2.50

Conclusions

The following points should be stressed:

(1) The octoploid line from the University of Manitoba showed one of the lowest percentages (15) of aneuploidy so far reported. The frequency of univalents in M-1 was in accordance with the value given to other octoploid lines.

(2) In spite of a high frequency of univalents, our hexaploid triticale showed a high fertility.

(3) The high yield in F_1 plants, the rapid decrease of the univalents' number in F_2 to F_4 generations, as well as the clear tendency toward the hexaploid level, could have been the result of the continuous search for plants with phenotypes resembling those of hexaploid lines.

Preliminary Report on the Cytogenetics of Tetraploid × Diploid Wheat Crosses[1]

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METZGER, R. J., AND B. A. SILBAUGH. 1974. Preliminary report on the cytogenetics of tetraploid × diploid wheat crosses, p. 181–185. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Selections of *Triticum durum* and *T. persicum* were crossed to *T. monococcum*. Twenty-six seeds were obtained from the backcross of the F_1 plants to *T. monococcum*. Chromosome counts of 20 plants showed that 16 had 6 bivalents plus 9 univalents, or 7 bivalents plus 6–8 univalents. Each of the remaining four plants had 14 pairs of chromosomes. Because the F_1 plants failed to produce seeds without pollination, we believe a form of apomixis, pseudogamy, was involved in the origin of the four tetraploid plants. These four plants are self-fertile and exhibit characteristics of both parents. They will be used to expedite the transfer of desirable genes from *T. monococcum* into tetraploid and hexaploid wheats.

Sixteen of the 20 plants apparently resulted from the fertilization of eggs carrying 13 or 14 univalents. Apparently eggs carrying less chromosomes than 13 univalents were not fertilized or the young embryos aborted. Regardless of the cause, failure to obtain seeds carrying less than 20 chromosomes suggests it will be difficult if not impossible to develop a line carrying the A genome substituted into the cytoplasm of tetraploid wheats.

Résumé Des sélections de *Triticum durum* et de *T. persicum* ont fait l'objet de croisements avec *T. monococcum*. Le comptage des chromosomes de 20 plants a révélé que 16 d'entre eux comportaient 6 bivalents et 9 monovalents, ou 7 bivalents et 6–8 monovalents. Chacun des quatre plants restants comportait 14 paires de chromosomes. Etant donné que les plants F_1 n'ont pu produire de grains sans pollinisation, nous estimons qu'une forme d'apomixie, de pseudogamie, est intervenue à l'origine des quatre plants tétraploïdes. Ces quatre plants sont autogames et possèdent les caractères de leurs deux parents. On les utilisera pour activer le transfert des gènes désirables de *T. monococcum* aux blés tétraploïdes et hexaploïdes.

Il semble que 16 des 20 plants soient issus de la fécondation de noyaux comportant 13 ou 14 monovalents. Il semblerait que les noyaux comportant moins de 13 mono-

[1]Contribution of the Agricultural Research Service, U.S. Department of Agriculture, and the Agronomic Crop Science Department, Oregon Agricultural Experiment Station, Corvallis, Oreg. 97331.

valents ne soient pas fécondés ou que le jeune embryon avorte. Quelle qu'en soit la cause, le fait que l'on n'ait pu obtenir de grains comportant moins de 20 chromosomes laisse à penser qu'il est difficile, sinon impossible, de créer une lignée introduisant le génome A substitué dans le cytoplasme des blés tétraploïdes.

MANY selections of diploid wheat, *Triticum boeoticum* and *T. monococcum*, are resistant to one or more of the diseases that infect tetraploid and hexaploid wheats. Attempts to transfer resistance from diploid into tetraploid and hexaploid wheats have been seriously hampered by both female and male sterility of F_1 hybrids (Szalai and Belea 1962). All of the systems proposed to circumvent the sterility problem are complex and only a few seeds are produced each generation. Consequently, the probability that the desired genetic recombinants will be recovered in the advanced generations is very small.

Kihara et al. (1956) reported seed could be obtained from crosses of *T. persicum* × *Aegilops squarrosa* as a result of union of unreduced gametes. Metzger and Silbaugh (unpublished data) obtained seeds from a cross of *T. durum*, selection D6644 × *Secale cereale*, cult Antelope, which apparently resulted from the union of unreduced gametes.

Mann and Lucken (1970) reported cytoplasmic male sterility results when the AB or ABD genomes are substituted into cytoplasm of diploid wheats. Possible effects of tetraploid or hexaploid cytoplasm on the A genome have not been determined.

The objectives of the investigations covered in part by this preliminary report are: (*a*) to determine if the restitution process, followed by union of unreduced gametes, can be used to move genes from diploid into tetraploid wheats; (*b*) to determine if the A genome can be substituted into the cytoplasm of tetraploid wheats; and (*c*) to check for cytoplasmic–genome interactions.

Materials and Methods

Crosses were made between four diploid and four tetraploid species (Table 1). Two of the diploid lines (P.I. 167556 and W491 -3) are resistant to all known races of common bunt, *Tilletia caries* and *T. foetida*. Selections W49-23 and 55B2.150 are susceptible. Saragolla, *T. durum*, is susceptible to bunt and it crosses readily with diploid wheats. *T. persicum* var. *stramineum* (hereafter designated T. per-5) is susceptible to bunt, crosses readily with diploid wheats, and, in crosses with *Ae. squarrosa*, seeds are produced by union of unreduced gametes (Kihara et al. 1956; Metzger and Sibaugh, unpublished data).

TABLE 1. Total number of tetraploid × diploid F_1 plants produced, number used as female parents in backcrosses to diploid wheats, and number of backcross seeds obtained.

Tetraploid (female)	×	Diploid (male)	No. F_1 plants: Total	No. F_1 plants: Used in crosses	F_1 flowers pollinated by: W49-23 Florets	W49-23 Seeds	55B2.10 Florets	55B2.10 Seeds
Saragolla	×	W49-1-3	38	5	3400	1		
"	×	P.I. 167556	76	10	3700	0	1500	0
"	×	W49-23	5	2	600	0		
"	×	55B2.150	1	1	500	0		
T. persicum var. *stramineum*	×	P.I. 167556	22	5	1500	4		
"	×	P.I. 167556	22	5	800	0	400	0
NB69864	×	W49-23	27	8	2400	10		
D6644	×	P.I. 167556	21	6	1600	3	1800	7
"	×	55B2.150	1	1	400	0		

Selection NB69864, *T. durum,* is a semidwarf winter type that crosses readily with diploid wheats. Its reaction to bunt is unknown. D6644, *T. durum,* crosses easily with diploid wheats and some selections of *Secale cereale* (Metzger and Silbaugh, unpublished data). We have failed in our attempts to cross D6644 with *Ae. squarrosa.*

The crosses and number of F_1 plants grown are listed in Table 1. The tetraploid parent was used as the female in each cross. Five to seven spikes on each of 32 F_1 plants were pollinated with pollen from diploid lines (Table 2). Twenty-four seeds were harvested from an estimated 10,000 pollinations. These seeds were sown and the plants were again crossed to diploid wheats (Table 2).

Pollen mother cells (PMC's) were collected from F_1 plants and from 21 of the 25 backcross plants. Chromosome numbers were determined for representative F_1 plants of each cross and for 20 of the 25 backcross plants.

Results and Discussion

An analysis of chromosome numbers of the F_1 plants representing all five crosses revealed six pairs of chromosomes, seven univa-

TABLE 2. Chromosome numbers of backcross F_1 plants of (tetraploid × diploid) F_1 × diploid wheats and number of seeds produced by florets pollinated by diploid wheats and selfed or open-pollinated flowers.

Plant no.	Backcross F_1: (Tetraploid × diploid)F_1 × diploid	Chromosome no.	BC F_1 × diploid: Florets pollinated	BC F_1 × diploid: Seeds	BC F_1 selfed or open-pollinated: Florets	BC F_1 selfed or open-pollinated: Seeds	BC F_1 selfed or open-pollinated: % set
G73- 2374	(Saragolla × W49-1-3) F_1 × W49-23		322	22	280	0	
2370	(T. per-5 × P.I. 167556) F_1 × W49-23	6″ + (2′) + 6′	96	1	1068	0	
2371	″ ″ ″	7″ + 7′	372	1	729	0	
2372	″ ″ ″	6″ + 9′	958	0	332	0	
2373	″ ″ ″	7″ + 6′	186	0	204	0	
2351	(NB69864 × W49-23) F_1 × W49-23		52	0	468	0	
2352	″ ″ ″	7″ + 8′	306	0	464	0	
2353	″ ″ ″	7″ + 8′	192	0	564	0	
2354	″ ″ ″		312	1	364	0	
2355	″ ″ ″	7″ + 7′	326	0	118	0	
2356	″ ″ ″	7″ + 6′ to 8′	380	0	330	0	
2357	″ ″ ″	7″ + 8′	202	0	316	0	
2358	″ ″ ″	6″ + 9′	318	1	642	0	
2359	″ ″ ″	7″ + 8′	316	0	320	0	
2376	″ ″ ″	7″ + 8′	444	0	460	0	
2361	(D6644 × P.I. 167556) F_1 × W49-23		126	0	334	0	
2362	″ ″ ″	7″ + 8′	118	0	186	0	
2363	″ ″ ″	7″ + 7′	296	2	238	0	
2364	(D6644 × PI. 167556) F_1 × 55B2.10	14″	40	1	652	247	38
2365	″ ″ ″	14″	48	6	737	680	93
2366	″ ″ ″	14″			530	523	99
2368	″ ″ ″	14″			518	502	97
2360	″ ″ ″				328	0	
2367	″ ″ ″	6″ + 9′	62	1	356	0	
2369	″ ″ ″	7″ + 8′	188	0	272	0	

lents plus two univalents that frequently were attached by a thin thread of chromatin. Since the tetraploid and diploid parents have the A genome in common, we believe the six pairs plus the two univalents that were frequently associated represented the A genome chromosomes. Because one pair of the A chromosomes did not pair regularly, those two univalents were free to move to either pole at Anaphase I somewhat independently. Without exception the F_1 plants used in this study were vigorous and completely male sterile (Table 1). Information obtained from crosses of the F_1 plants with diploid lines (hereafter called backcrosses) follows.

(Saragolla × W49-1-3) F_1 × W49-23

Although an estimated 3400 F_1 florets were pollinated with pollen from diploid plants, only one seed was set. The backcross plant grown from this seed was completely male sterile (Table 2). When it was crossed again to diploid wheats, 22 seeds were produced from 322 hand-pollinated florets. No seeds were produced by the 280 florets that were allowed to self- or open-pollinate. Sporocytes collected from this backcross plant, and analyzed much later, were found to have already undergone meiosis. Numerous micronuclei were observed in most of the immature pollen grains, which suggested the plant was an aneuploid carrying one or more univalents. We believe this plant resulted from the fertilization of an egg carrying the AB genomes with a male gamete carrying the A genome of the diploid parent. Phenotypically, the backcross plant was similar to the F_1, which was used as the female.

(T. per-5 × P.I. 167556) F_1 × W49-23

Four seeds were obtained from an estimated 1500 F_1 flowers pollinated with pollen of diploid wheat. Phenotypically, three of the four plants grown from these seeds were similar to the F_1 plants. These plants had chromosome counts of 7″ + 7′, 6″ + 9′, and 7″ + 6′, respectively (Table 2). The fourth backcross plant, G73-2370, exhibited many characteristics of diploid wheat, *T. monococcum*, yet it had six pairs of chromosomes plus eight univalents. Two of the univalents were infrequently joined by a thread of chromatin, which suggested they belong to the A genome. If true, the F_1 egg that was fertilized to give rise to this plant was apparently short one of the B chromosomes.

These four backcross plants were crossed again to diploid lines. Two seeds were obtained from 1612 pollinations (Table 2). All of the 2340 flowers that were allowed to self- or open-pollinate failed to set seed.

(D6644 × P.I. 167556) F[1] × W49-23

Ten backcross seeds were harvested from an estimated 2400 F_1 florets pollinated with pollen of diploid wheats. The 10 plants grown from these seeds were phenotypically similar to the original F_1 plants. Chromosome numbers were determined for 8 of the 10 plants (Table 2). Five of the eight plants had seven pairs of chromosomes plus eight univalents. This suggests eggs carrying 15 univalents were fertilized by 7x male gametes. Because trisomics were not observed in the metaphase I plates, we assumed the extra univalent represented the chromosome from the A genome of NB69864 that paired infrequently in the F_1 plants. Apparently the eggs carried both chromosomes of that pair, one contributed by W49-23 and one by NB69864.

Chromosome numbers of the remaining three backcross plants were 7″ + 7′ (G73-2355), 7″ + 6′ to 8′ (G73-2356), and 6″ + 9′ (G73-2358) (Table 2). The A genome chromosome of the tetraploid parent that failed to pair in F_1 plants was apparently omitted from the egg fertilized to produce plant G73-2355.

An attempt was made to again backcross all 10 F_1 plants to diploid wheats. Two seeds were obtained from 2848 pollinations. This suggests the frequency of restituted female gametes or gametes, or both, carrying the A genome alone is very low. Flowers allowed to self or outcross failed to set seed.

(D6644 × P.I. 167556) F_I × W49-23

Three seeds were harvested from an estimated 1630 hand-pollinated flowers (Table 2). Chromosome numbers for two of the three plants are also listed in Table 2. Phenotypically all three plants were similar to the original F_1 plant. Plants G73-2362 and G73-2363 were crossed again to diploid wheats. Two seeds were obtained from 540 florets. This again suggests restitution occurred infrequently in the backcross plants.

(D6644 × P.I. 167556) F_1 × 55B2. 10

Phenotypically, the seven backcross plants, obtained from an estimated 1800 pollinations, fell into two classes: self-fertile and self plus cross-sterile. Four of the plants had 14 pairs of chromosomes and were self-fertile (Table 2). Seed set under bags ranged from 38% on plant G73-2364 to 99% on plant G73-2366. The origin of these four tetraploid plants is not clear. The F_1 plants were male sterile and failed to produce seeds when allowed to self-pollinate. It appears, therefore, that pollination was necessary for the formation of germinable backcross seeds. We suspect the unreduced egg cells were not fertilized but the male gamete united with the fusion nucleus to give rise to the endosperm. Apomicts of this type are not uncommon. Such pseudogamous species occupy an intermediate position between normally sexual species and typical apomicts, in which pollination is unnecessary (Muntzing 1967). In order for eggs carrying 14 pairs of chromosomes (AB genomes) to be produced, one must assume the first meitotic division was completed and that restitution occurred at telophase I. This would account for the loss of seven nonhomologous chromosomes of the A genome. Crossing over between homologous A genome chromosomes and the inclusion of one or more chromosomes of the diploid parent in eggs carrying 14 chromosomes would allow genes to be transferred from the diploid parent into the new apomictically produced tetraploids.

Backcross plant G73-2367 had six pairs of chromosomes plus nine univalents. One seed was obtained from the pollination of 62 florets with *T. monococcum* pollen. Seven pairs of chromosomes plus eight univalents were observed in PMC's of plant G73-2369. The chromosome number was not determined for plant G73-2360. Because it was both self- and cross-sterile and phenotypically approached the F_1, we believe it had either $7'' + 7'$ or $7'' + 8'$.

The recovery of tetraploids among the backcross plants of (D6644 × P.I. 167556) F_1 × 55B2.10 indicates genes can be transferred from diploid lines of *T. monococcum* into tetraploid wheats as a result of either pseudogamy or the union of unreduced gametes. Because no seeds were produced by florets allowed to self-pollinate, the union of unreduced gametes appears unlikely. Seeds were set following pollination, which suggests unreduced eggs gave rise to embryos and the endosperms resulted from the union of the male gamete with the fusion nucleus.

Sixteen of the 20 plants checked cytologically resulted from the pollination of eggs carrying 13–15 univalents with pollen from the diploid parent. Apparently eggs carrying the A genome along were nonfunctional. This suggests it will be extremely difficult if not impossible to substitute the A genome of diploid wheats into tetraploid cytoplasm. We propose to continue backcrossing plants carrying $7'' + 7'$ to *T. monococcum*. After backcrossing for several generations, the A genome of these plants will be in the main of *T. monococcum* origin. Eggs carrying the A genome from these plants may be functional.

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Triticale Diseases Review

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FUENTES, SANTIAGO FUENTES. 1974. Triticale diseases review, p. 187–192. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The major triticale diseases described in this paper include powdery mildew, wheat streak mosaic virus, leaf rust, ergot, bacterial stripe, and stem rust.

Information is scant on powdery mildew but triticales in Hungary have been found highly resistant.

Tests in the United States have shown that triticales are symptomless carriers of the wheat streak mosaic virus.

Leaf rust has been reported since the 1940's and studies have shown that resistance is controlled by a single dominant gene present in each of the triticales tested. *Puccinia recondita tritici* is the causal agent.

Ergot is one of the most important diseases of triticales due to toxicity of the sclerotia produced by the fungus and the susceptibility of many triticale cultivars. Trials have indicated that Kenya Farmer and Carleton cultivars are more resistant than Manitou or Stewart 63.

Since 1968, bacterial stripe has been observed on triticales, durums, and rye, causing severe striping in the leaves with abundant exudate under humid conditions. The disease is now found only sporadically throughout the CIMMYT nursery.

As a result of trials attempting to characterize stem rust of triticales, isolates were assigned to *Puccinia graminis* f.sp. *tritici*, *P. g.* f.sp. *secalis*, and *P. g.* n.f.sp. *triticalis*.

Several other diseases of epidemic proportions observed yearly in the CIMMYT summer nursery in the Valley of Toluca, Mexico State, are discussed as well.

Résumé Les principales maladies du triticale décrites dans ce texte sont l'oïdium des céréales, la mosaïque virale bigarrée du blé, la rouille des feuilles, l'ergot, la maladie des stries bactériennes et la rouille de la tige.

On ne dispose que de peu de renseignements sur l'oïdium, mais les triticales s'y sont révélés très résistants en Hongrie.

Les essais effectués aux Etats-Unis ont permis de constater que les triticales sont des vecteurs inapparents de la mosaïque virale bigarrée du blé.

On a signalé depuis les années 1940 les manifestations de la rouille des feuilles et les études faites ont démontré que la résistance des triticales dépend d'un seul gène dominant dont on a constaté la présence dans les variétés soumises aux essais. L'agent causal de cette rouille est *Puccinia recondita tritici.*

L'ergot est l'une des maladies les plus graves du triticale, à la fois du fait de la toxicité des sclérotes produites par le champignon et de la sensibilité de nombreux cultivars de triticale. Les essais ont révélé que les cultivars Kenya Farmer et Carleton sont plus résistants que le Manitou et le Steward 63.

On a constaté depuis 1968 l'apparition de la maladie des stries bactériennes sur le triticale, le blé dur et le seigle. Elle provoque sur les feuilles des stries prononcées qu'accompagne une exsudation abondante lorsque les conditions sont humides. Cette maladie ne se manifeste encore que d'une façon sporadique dans les pépinières du CIMMYT.

A la suite des essais de détermination des rouilles de la tige sur triticale, on a réussi à isoler *Puccinia graminis* sp. c. *tritici*, *P. g.* sp. c. *secalis*, et *P. g.* sp. n.c. *triticalis*.

Le texte traite également de plusieurs autres maladies d'allure épidémique observées au cours des ans à la pépinière d'été du CIMMYT de la vallée de Toluca, dans l'Etat de Mexico.

OUR knowledge on triticale diseases is rather scarce as such diseases have been studied only in the last two decades because of the renewed interest in developing triticales as a commercial crop.

From the literature available in the agricultural libraries in Mexico, a list of diseases was obtained (Table 1).

Diseases

Powdery Mildew

Although the information is scant for powdery mildew, Maninger (1969) indicated that triticales in Hungary are highly resistant to this disease.

Wheat Streak Mosaic Virus

The wheat streak mosaic virus was studied by Gardner and coworkers (1969) at the South Dakota State University in 1969. A virus extract from infected wheat plants was blasted into triticale and wheat control plants. As far as visible disease symptoms were concerned all wheat plants were completely susceptible, whereas the triticales were immune. In further testing of the inoculated triticales, the presence of virus (detected by index plants) was demonstrated in percentages varying from 3 to 93. This, apparently, is a case in which triticales are symptomless carriers of the wheat streak mosaic virus.

Leaf Rust

Leaf rust in triticales has been reported since the 1940's (Chester 1946; Larter et al. 1969). Quiñones (1971) studied the inheritance of resistance to leaf rust in hexaploid triticales. The reaction of the hexaploids 6A-190, Rosner, Armadillo, Bronco, and Toluca 160 to five leaf rust isolates (one from rye, four from wheat) was first determined. Later

TABLE 1. Diseases of triticale.

Common name	Causal agent	Reference
Leaf rust	*Puccinia recondita*	Chester 1946; Larter et al. 1969; Quiñones 1971; Rajaram 1971
Ergot	*Claviceps purpurea*	Larter et al. 1968; Platford and Bernier 1970
Bacterial stripe	*Xanthomonas translucens*	CIMMYT's Annual Report 1969–70
Powdery mildew	*Erysiphe graminis* (?)	Maninger 1969
Wheat streak mosaic	Virus	Gardner et al. 1969
Stem rust	*Puccinia graminis tritici*	López 1971
Yellow rust	*Puccinia striiformis*	Zillinsky and Borlaug 1971
Head blight	*Fusarium* spp.	CIMMYT's Annual Report 1971–72
Septoria leaf blotch	*Septoria tritici*	CIMMYT's Annual Report 1971–72
Downey mildew	*Sclerophthora macrospora*	Troutman and Matejka 1972
Leaf blight	*Fusarium nivale*	Richardson and Zillinsky 1972
Loose smut	*Ustilago tritici* (?)	Not described

on, the tricales were intercrossed and backcrossed to a susceptible parent and the populations F_1, F_2, and F_3 were inoculated with race 15 of *Puccinia recondita tritici.* The analysis of the resistant-vs.-susceptible segregants indicated that resistance to leaf rust was controlled by a single dominant gene present in each of the triticales tested. Quiñones concluded also that "genes governing resistance to leaf rust were derived from the wheat parent, and resistance carried by the rye parent was not expressed in the amphiploid Triticale."

In 1972, Rajaram at CIMMYT presented evidence that *P. r. tritici* is the causal agent of the leaf rust symptoms in triticales (Anon. 1971–72). His work is summarized in Table 2. Rajaram et al. (1971) also inoculated 125 hexaploid and octoploid triticales with common isolates of *P. r. tritici.* Thirty-three genotypes were resistant at seedling and adult plant stages, 56 were susceptible at both stages, and 19 lines indicated susceptible reactions as seedlings and resistance in adult plants either in the greenhouse or under field conditions.

The reaction of a portion of these 19 triticale lines to leaf rust cultures 310 and 321 in the greenhouse is detailed in Table 3.

The susceptibility in seedlings and resistance in adult plant stage is one criterion to suspect the presence of generalized resistance. Thus, the evidence presented here opens new possibilities for a more stable type of resistance against leaf rust in hexaploid and octoploid triticales.

Ergot, along with the rusts, remains the most important disease of triticales due to the toxicity of the sclerotia produced by the fungus and the susceptibility of many triticale cultivars. Platford and Bernier (1970) from the University of Manitoba, Winnipeg, Man., Canada, tested the reactions of four wheat cultivars, prospective parents for triticales. The results appear in Table 4.

TABLE 2. Pathogenicity of *Puccinia recondita* on triticales.

Rust isolates	Reaction on Rye	Reaction on Wheat	Reaction on Triticales
From rye (*P. recondita* f.sp. *secalis)*	Susceptible	Immune	Immune
From wheat (*P. recondita* f.sp. *tritici)*	Susceptible (mostly)	Susceptible	Susceptible

TABLE 3. Reaction of triticale genotypes to two isolates of *Puccinia recondita tritici.*

Genotypes	Seedling reaction		Adult plant reaction	
	Cult 310	Cult 321	Cult 310	Cult 321
	Hexaploid triticales			
Armadillo "S"	4	3+	5MR	10MR
Bronco "S"	4	4	5MR	20MR
Grillo "S"	4	4	10MR	10MR
UM940-S	3	4	5MR	5MR
Tcl. My64–UM940-S	3	3	20MR	20MR
UM940-S–Tcl. My64	3+	4	20MR	20MR
	Octoploid triticales			
Inia 66–Guarda	3+	4	10MR	20MR
Penjamo 62–Polko Rye	3+	3+	5MR	5MR

Kenya Farmer (a hexaploid wheat) and Carleton (durum) were more resistant to ergot than Manitou or Stewart 63. Resistance was measured by fewer sclerotia per florets, by smaller sclerotia, and by less sugary exudate in the florets. As a preliminary recommendation Kenya Farmer and Carleton may be used in crosses to induce resistance to ergot in triticales.

Bacterial Stripe

Bacterial stripe due to *Xanthomonas translucens* has had a peculiar history in Mexico. It has been observed since 1968 on triticales, durums, and rye causing a severe striping in the leaves with abundant exudate under humid conditions. The disease damaged the summer and winter triticale nurseries at Navojoa, Sonora State, and El Batan, Mexico State (Zillinsky and Borlaug 1971).

An estimate of losses caused by bacterial stripe was made out of some yield experiments in the season 1969–70 (Table 5).

Some Armadillo "S" lines and early sown materials were among the most affected in regard to test weight and yield. At this point, a screening of genotypes was attempted to incorporate genes for resistance into advanced triticale lines. The disease, however, has disappeared gradually after 1970, and in the past summer and winter seasons it was found sporadically throughout the nursery.

TABLE 4. Reaction of wheat genotypes inoculated with one isolate of *Claviceps purpurea* from wheat.

Genotype	% florets w/sclerotia	Size of sclerotia	Relative amount honey dew produced
Manitou (bread wheat)	70	2	3
Kenya Farmer (bread wheat)	26	1	1
Stewart 63 (durum)	78	3	4
Carleton (durum)	42	1	2

Stem Rust

An effort to characterize the stem rust of triticales was made by López in 1971. Collections of stem rust from wheat, rye, and triticale were inoculated on the same hosts with the following results:

(1) Three rust isolates from wheat and eight from triticales produced various resistance to susceptible reactions on the three hosts. These isolates were assigned to *Puccinia graminis* f.sp. *tritici*.

(2) The isolates from rye attacked only rye and belonged to *P. g.* f. sp. *secalis*.

(3) One isolate (#39) from rye and 11 isolates from triticales produced susceptible reactions on the three hosts. Since the behaviour of these isolates did not follow that of any known rust, the author proposed a new *forma specialis* to designate them: *P. g.* n.f.sp. *triticalis*.

Others

Several diseases of epidemic proportions can be observed yearly in the CIMMYT summer nursery in the Valley of Toluca, Mexico State (2640 m elevation, cool climate, and abundant rains and dew from late May to October).

Yellow rust — Yellow rust caused by *Puccinia striiformis* causes severe damage to bread wheats, durums, barleys, and triticales. Early in the development of CIMMYT's triticale program in 1964, several very susceptible triticale lines were produced. At present,

TABLE 5. Effects of bacterial stripe on triticales, Navojoa, Sonora, Mexico, 1969–70.

Test	Yield, *g/plot*		Test wt, *kg/hl*	
	Mid-variety in test	Infected triticale strains, avg	Mid-variety in test	Infected triticale strains, avg
I	1153	860	71.9	69.7
III	913	801	71.5	65.9
V	940	533	70.5	61.2
VII	1005	643	69.0	67.6

through constant screening and the crossing of resistant progenitors, most of the genotypes used in the basic nursery of triticales are highly resistant to yellow rust.

Head blight — Another disease found in the same area is the head blight (*Fusarium* spp., possibly *F. roseum*), particularly severe on durums and triticales. Symptoms consist of a premature drying of the glumes, poor grain development, and the presence of a rose-coloured layer of fungus spores at the base of the glumes. Since the problem is of local importance, no special effort for breeding against head blight has been made in triticales other than the elimination of the most susceptible genotypes.

Spotting — *Fusarium nivale*, recognized by Richardson and Zillinsky in 1972 also in the Toluca Valley, produces a severe spotting of the foliage of triticales, durums, and some bread wheats. This is the first report of the presence of this fungus south of its present geographical distribution. In northern latitudes *F. nivale* is the "snow mold" responsible for the killing of winter wheats and grasses.

Leaf blotch — *Septoria tritici* is the cause of leaf blotch in wheat, a disease threatening commercial crops of bread wheats and durums in North Africa, the Middle East, Brazil, and Argentina. The lesions on the leaves consist of necrotic spots, rectangular in shape, with a faint yellowish halo and abundant fruiting bodies (pycnidia) visible as small black dots.

In the *Septoria* nursery in Mexico (Pátzcuaro, Michoacan State) triticales were highly resistant (Anon. 1971–72). Some necrotic spots can be found in the lower leaves of the plants but the amount of fungus fructifications is very small. A fairly typical reaction of the triticale lines included in the International Triticale Screening Nursery, 1972, is shown in Table 6.

Even though triticales are resistant under Mexican conditions, it is not known whether the resistance will be maintained in other areas of the world such as North Africa, the Middle East, or South America. In these areas, bread wheats and durums (both in the background of triticales) are heavily attacked by strains of *Septoria tritici*, assumedly different in virulence to those strains present in Mexico.

TABLE 6. Reaction of triticale lines to *Septoria tritici* as compared to durum and bread wheats, Pátzcuaro, Michoacan, Mexico, summer 1972.

Genotypes	Septoria rating, scale 0–9
Maya II – Armadillo "S"	1R
Inia 66 – Guarda × Armadillo "S"	2R
Armadillo	2R
Inia 66 – Armadillo	2R
Badger – Calidad	4R
Armadillo "S" – Rye T33	2R
Inia 66 (bread wheat)	7S
Siete Cerros (bread wheat)	6S
Cocorit 71 (durum)	4MR-MS
Jori 69 (durum)	4MR-MS

Downy mildew (Sclerophthora macrospora) — This has been recognized in commercial fields of triticales in southwestern Arizona in the United States, causing no appreciable damage to the crop (Troutman and Matejka 1972). Symptoms of this disease are very characteristic: thickening of tissues that brittle, and severe distortion of the head with excessive proliferation of the floral bracts. No grain is produced. In northwestern Mexico downy mildew is also found sporadically in triticales along irrigation ditches.

Smut — A disease recently recognized is smut. One infected triticale plant was detected by CIMMYT's research group at the Toluca nursery, Mexico, in the summer of 1973. All tillers showed infection along with a certain amount of dwarfness of the plant. The spikes were replaced, partially or in total, by black masses of spores easily dispersed by the wind. Under the microscope the spores had an uneven distribution of the pigment and prominent ornamentations in the cell wall. The symptoms resembled those of loose smut caused by *Ustilago*. If such is the case, artificial inoculations of bread wheats, ryes, barleys, and triticales by injecting a spore suspension on the flowers after anthesis should result in infected plants in the following crop season.

Conclusions

In concluding this review on diseases of triticales it should be pointed out that pathologists continue to recognize and study the pathogens responsible for diseases. In a few instances, such as ergot and leaf rust, there is evidence for resistance either in hexaploid or octoploid triticales or in the progenitors species. In the future, as triticales become a commercial crop distributed in a wide array of ecological conditions in the world, some diseases may become epidemic and destructive, lowering yields or quality, or both, of the grain. Without question, efforts for building up resistance to diseases must be intensified.

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Triticale Diseases in CIMMYT Trial Locations

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RICHARDSON, M. J., AND J. M. WALLER. 1974. Triticale diseases in CIMMYT trial locations, p. 193–199. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract This paper describes triticale diseases found by the staff of CIMMYT at their various trial locations in Mexico, records made by cooperators in outreach trials, and the authors' examination of material at and from CIMMYT. At present, a list of pathogens capable of infecting triticale is all that can be attempted. This list will doubtless increase as the crop is grown more widely and receives more attention from plant pathologists throughout the world. Little can be said about the different susceptibilities of triticale to various diseases. Information available from the International Triticale Yield Nurseries on disease incidence is very incomplete, but it would appear that in general triticale has some useful resistance against stem rust (*Puccinia graminis* Pers.) and stripe rust (*P. striiformis*) but is somewhat susceptible to leaf rust (*P. recondita* Rob. ex Desm.). In North Africa and South America triticale has some resistance to septoria disease, which can be severe on wheat in these areas. Estimation of disease severity in terms of yield loss will require more intensive research that can only be contemplated when triticale is more extensively grown.

Résumé Ce texte décrit les maladies du triticale constatées par les chercheurs du CIMMYT aux différents endroits du Mexique où sont situés les champs d'essai, celles signalées par les collaborateurs du Centre dans les essais de diffusion et celles relevées par l'auteur lors d'examens du matériel végétal du CIMMYT ou provenant de cet organisme. Une liste de pathogènes susceptibles d'infecter le triticale est tout ce que l'on a pu établir jusqu'à présent. Cette liste s'allongera sans aucun doute au fur et à mesure que se répandra cette culture et qu'elle bénéficiera de plus d'attention de la part des phytopathologistes du monde entier. On ne peut dire que peu de choses quant à la vulnérabilité des triticales aux différentes maladies. Les renseignements sur la fréquence des maladies émanant des pépinières internationales de multiplication du triticale sont très incomplets, mais il semblerait qu'en général les triticales aient une bonne résistance à la rouille de la tige (*Puccinia graminis* Pers.) et à la rouille striée (*P. striiformis*) mais soient assez sensibles à la rouille des feuilles (*P. recondita* Rob. ex Desm.). Le triticale a révélé une certaine résistance à la septoriose en Afrique du Nord et en Amérique du Sud, régions où cette maladie peut gravement affecter le blé. Un jugement sur la gravité des maladies en termes de pertes de production nécessitera des recherches plus intensives qui ne pourront être envisagées que lorsque la culture du triticale se sera développée sur une grande échelle.

TRITICALE has been grown commercially in Hungary, Spain, Canada, and parts of the USA, but there are few references to disease apart from rusts and ergot, which were covered by Fuentes (1974). Our information on triticale diseases is limited to observations made in Mexico by the staff of CIMMYT at their various trial locations, records made by cooperators in outreach trials, and our own examination of material at and from CIMMYT. Many of these observations are of limited use because of the difficulty of disease diagnosis. Very similar symptoms may be caused by different pathogens in different parts of the world and the same pathogen may express itself in a variety of ways. All trial workers and breeders should be prepared initially to make some preliminary microscope examination of diseased material to determine the identity of the pathogen. Attempts at field diagnosis should only be made when one is familiar with the symptoms of a disease in a particular area, and even these diagnoses should be supported by regular microscope checks. Whenever possible, the help of national or international pathological or mycological services should be used.

There is a well-defined group of organisms known to be pathogenic on wheat or rye, and it is likely that these organisms will eventually be found on triticale. Lesions with organisms not belonging to this group should be examined with care before being reported as a new disease, and efforts should be made to satisfy Koch's postulates. These state that an organism should be isolated into pure culture from lesions, be shown to be capable of reinfecting the host to cause the same disease, and be reisolated into pure culture.

For nonpathologists it would be useful to outline the main points to be noted when looking at fungi from diseased material. Hopefully spores will be present. Are they produced superficially or from inside spherical structures? The spherical structures may be superficial or immersed in plant tissue. If they contain free spores they are probably pycnidia (Fig. 1). If the spores are not free but are contained, usually in groups of eight within sacs (asci, Fig. 2) they are perithecia. For further identification, the shape, size, and colour of the spores need to be noted.

Leaf Diseases

Fusarium nivale (Fr.) Ces. (*Micronectriella nivalis* (Schaff.) Booth)

A leaf blight caused by this fungus occurs extensively at Toluca and also at El Batan, but it has not been recorded on triticale elsewhere, or to any extent on other cereals (Richardson and Zillinsky 1972); therefore, except at Toluca, it would seem to be of little importance at present. It should, however, be watched for in areas with a climate similar to that of Toluca, with relatively warm day temperatures, frequent heavy rain for spore dispersal, and long periods of leaf wetness for infection. Lesions are extensive, irregular, dull grey-green, and water-soaked in appearance. The fungus produces pustules of spores through each of the stomata, which can be seen with a hand lens ($\times 10$) as parallel rows of regularly spaced whitish to pinkish dots (Fig. 3). The spores are colourless, 10–30 (40) $\times$ 4–5.5 μm, curved, with 0–3 septa (Fig. 5). Very old lesions may also have the perithecial state.

Septoria Leaf Blotches

Much work has been done at CIMMYT with *Septoria tritici* Rob. and Desm., but there are three or four species of *Septoria* that may occur in different areas (Richardson and Noble 1970). Spores of all species are colourless, cylindrical, and produced in pycnidia.

The current position is as follows:

Septoria tritici, with spores 50–90 $\times$ 2 μm (Fig. 6), has been recorded from Mexico (Anon. 1973), Portugal and Tunisia (CIMMYT 1972), and Algeria (Floyd, personal communication). Lesions tend to be buff, irregular, and extensive, and speckled with small, dark pycnidia.

Septoria nodorum Berk. (*Leptosphaeria nodorum* Müller) is the common wheat pathogen in Europe, causing both leaf and glume blotch. The spores are short, rarely more than 25 μm long $\times$ 3–4 μm (Fig. 7). Pycnidia are

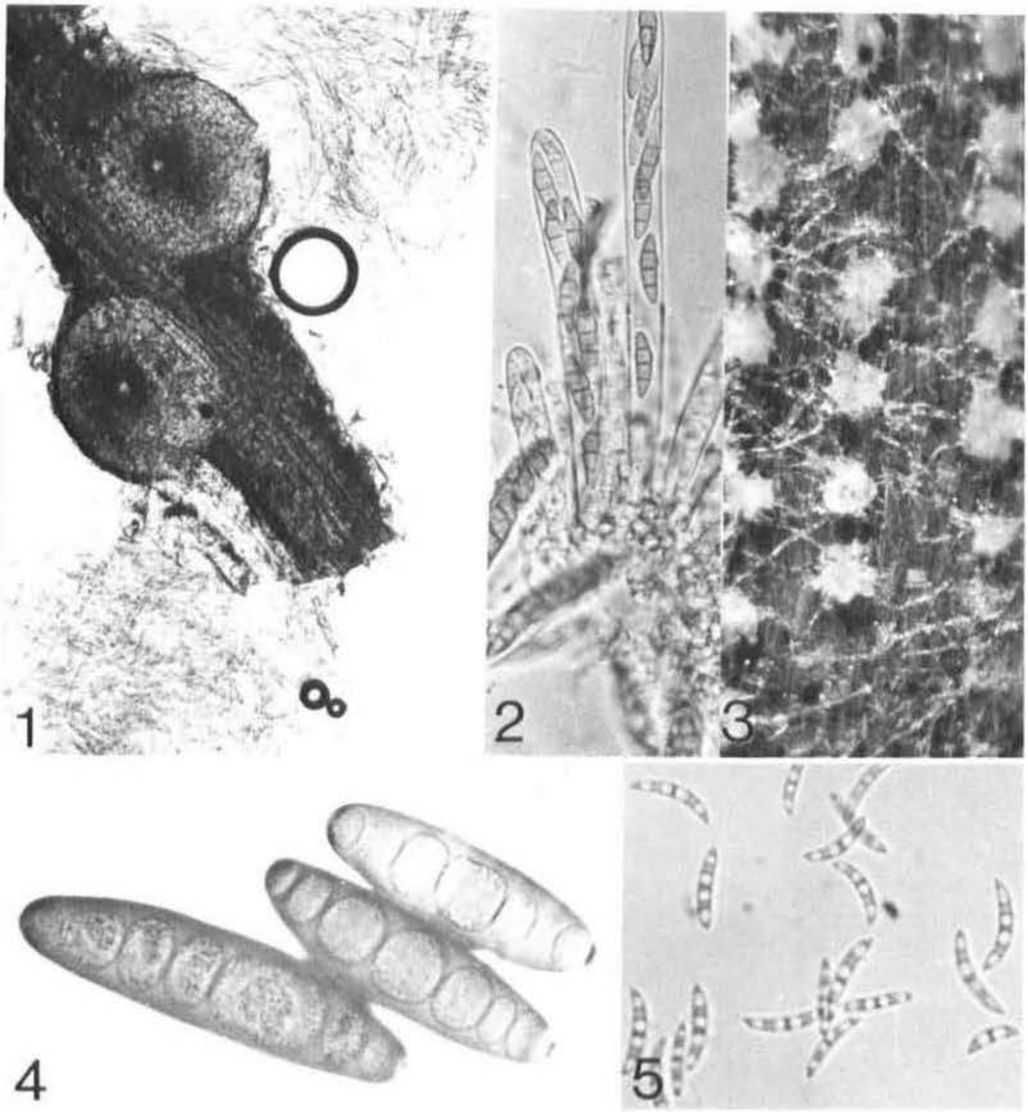

FIG. 1. Pycnidia (×84). FIG. 2. Asci (×336). FIG. 3. *Fusarium nivale* sporulation through stomata of leaf (×84). FIG. 4. *Drechslera sativa* spores (×630). FIG. 5. *Fusarium nivale* spores (×630).

often pinkish and transparent, but may become darker with age. It has been recorded on triticale in Tunisia (CIMMYT 1972) and at Toluca.

Septoria avenae f.sp. *triticea* Johnson (*Leptosphaeria avenaria* f.sp. *triticea* Johnson) is the wheat form of the oat *Septoria*. *Septoria secalis* Prill. and Delacroix occurs on rye. Both species have spores 30–50 × 3–4 μm (Fig. 8) and such spores have been obtained from triticale at El Batan and Toluca. Which of the two species is involved, if in fact they are distinct, cannot be ascertained until infection tests have been carried out. Lesions of *S. nodorum* and *S. avenae* f.sp. *triticea* on both wheat and barley, and *S. secalis* on rye can all be similar, often buff with chlorotic margins, but very dark lesions with *S.*

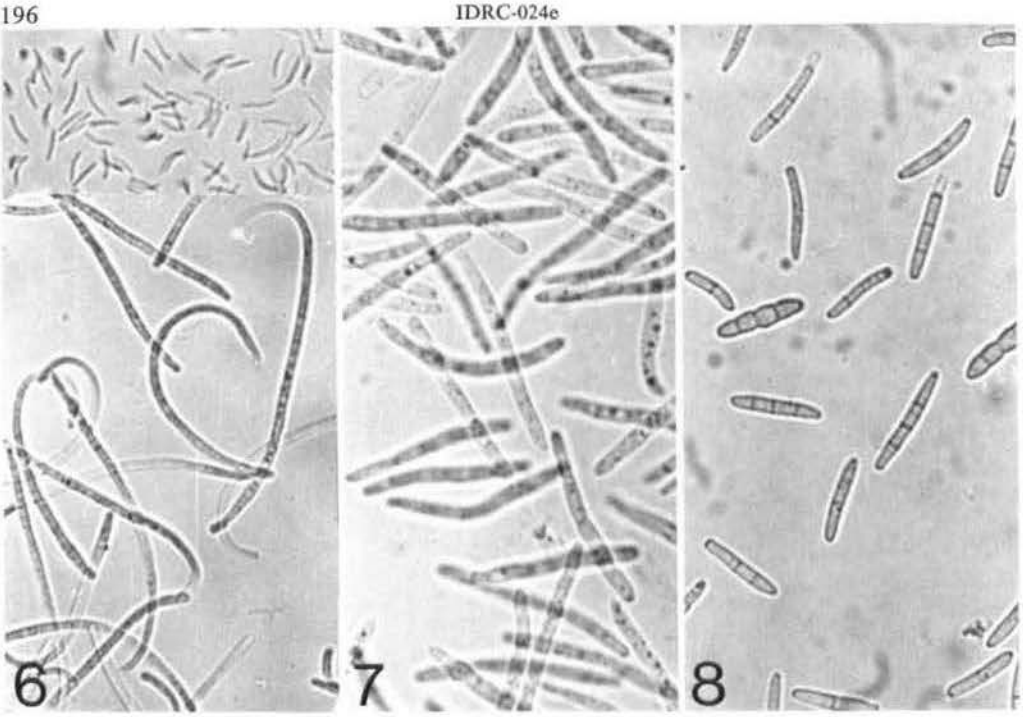

FIG. 6. *Septoria tritici* micro- and macro-spores (× 660). FIG. 7. *Septoria avenae* f.sp. *triticea* spores (×660). FIG. 8. *Septoria nodorum* spores (×660).

nodorum and *S. avenae* f.sp. *triticea* or *S. secalis* pycnidia have been observed on triticale from Toluca. Pycnidia are much less obvious than those of *S. tritici* and are best seen with transmitted light.

It is possible that some of the outreach records of *S. nodorum* are in fact records of this longer spored *S. avenae* f.sp. *triticea*/*S. secalis*. It is not widely known and there is a tendency to identify as *S. nodorum* any *Septoria* on wheat that is not obviously *S. tritici*.

Drechslera (Helminthosporium) sativa (Cochliobolus sativus (Ito and Kuribay) Drechsl. ex Dastur)

This fungus is a cosmopolitan cereal pathogen causing both a foot rot and leaf spot. It has been recorded on triticale collected from both Toluca and El Batan, and will no doubt be recorded in many places where triticale is grown. The leaf spot can be similar to those produced by *Septoria* spp., but the lesions produce large, superficial, dark-brown, septate, banana-shaped spores up to 120 × 18–25 μm (Fig. 4).

Two other leaf diseases that have not yet been recorded on triticale should be mentioned. *Rhynchosporium secalis* (Oud.) Davis causes scald of barley, but was first described from rye. Lesions are water-soaked with dark margins and produce colourless, beaked, two-celled spores abundantly over the surface. *Alternaria triticina* Prasada and Prabhu causes a leaf disease of wheat in India. *Alternaria* is a large genus and many species grow saprophytically on dead tissue, so it should not be assumed that any *Alternaria* associated with a lesion is either *A. triticina* or the cause of the lesion.

Nonpathogenic Abnormalities

Frequently, pathological symptoms that are not caused by pathogenic organisms occur on plants. Often these are confused with symptoms caused by known pathogens, thus obscuring the true cause of the condition and perhaps overestimating the effect of other diseases. These nonpathogenic abnormalities may be caused by adverse environmental conditions, such as mineral deficiencies or toxicities, moisture stress, temperature extremes, or they may be largely influenced by the genotype of the plant.

Environmental stresses that do not induce pathological symptoms may nevertheless predispose the plant to attacks by pathogenic organisms.

A prominent chlorotic leaf speckle occurs uniformly throughout Cinnamon triticale both at Toluca and El Batán. All attempts to isolate a pathogen that could be responsible for this have failed, and the condition appears to be an intrinsic character of the crop. The chlorotic speckling reduces the photosynthetic area of the leaves and later appears to facilitate the establishment of weakly pathogenic organisms that hasten leaf senescence.

Many species of fungi grow as saprophytes on leaf surfaces especially on areas of dead or moribund tissue. These do no harm, and it should not be assumed that any fungus seen in association with a lesion is the cause of it. *Alternaria* spp., *Cladosporium* spp., *Epicoccum,* sooty moulds, and yeasts are common leaf saprophytes that are very frequently seen growing on lesions primarily caused either by other fungi, viruses, or nonpathogenic causes.

Root and Stem Base Diseases

Generally, these diseases receive less attention than those affecting the aerial parts of the plant. This is largely because they are more difficult to observe and record; also they are usually reckoned to be less dangerous than leaf diseases and spread during a season is very small. Frequently root and stem base diseases are only noticed when they induce severe symptoms on the aerial parts of the plants, such as severe stunting, chlorosis, "white heads," etc. However, "subclinical" attacks producing no easily detectable aerial symptoms can restrict yields by reducing tillering, ear size, and grain weight.

Information on root and stem base diseases of triticale is at present very scant. Take all, *Gaeumannomyces (Ophiobolus) graminis* (Sacc.) Arx and Olivier, is locally severe in Armadillo PM 13 at El Batan but does not seem to be widespread. Krolow (personal communication) reports that take all occurs in triticale in Europe where the octoploids appear to be most susceptible. Eyespot *(Cercosporella herpotrichoides* Fron) also occurs there but has not been observed in Mexico, but *Rhizoctonia (Corticium) solani* Kühn was isolated from an ill-defined eyespot lesion at the base of the stem of a prematurely dead plant of Armadillo from El Batan. Fusarium foot rot has been reported from the USA and is doing some damage in triticale at El Batan where it is associated with *Cochliobolus (Helminthosporium) sativum,* a fungus frequently observed sporulating on moribund stem bases.

Insects and Other Pests

Very little information is available on pest attacks on triticale, although pests such as Hessian fly can be important on cereal crops in North Africa. Shoot flies are causing some damage at Toluca and El Batan, where grubs boring along the stem prevent ear emergence.

Bacterial Diseases

Bacterial leaf striping can be severe on some lines of triticale (e.g., Jenkins Foundation Research No. 6A/203) at El Batan, and has been very severe in Sonora in the past. However, selection of resistant lines at Navojoa has greatly reduced the problem. This disease also occurs on triticale in India and it would seem that the crop may be more susceptible than either wheat or rye. *Xanthomonas translucens* (Jones, Johnson and Reddy) Dowson has been reported to be the cause in most instances, but *Pseudomonas striafasciens* (Elliott) Starr and Burkholder has been isolated from bacterial leaf striping at El Batan.

Seed-Borne Fungi

Apart from the direct loss caused to the growing crop by disease there are two other aspects that should be mentioned. Many pathogenic fungi that occur extensively on cereal leaves can also infect the grain and so provide the fungus with an ideally placed inoculum to infect the seedlings produced when that seed is sown. Poor seed germination should not automatically be blamed on the genetic constitution of the line concerned. It may be the result of a high level of seed-borne inoculum. It may be the result of an attack of the seed or seedling by soil organisms. Seed that is in poor physiological condition because of poor harvesting, storage, or handling conditions is especially vulnerable to such attack when sown.

Seed treatment with fungicides can help to control both of these problems.

In the preliminary study, 13 seed stocks were examined in October 1973 for the presence of seed-borne pathogens, by plating out 100 seeds of each on potato dextrose agar after 10 min surface disinfection with 1% sodium hypochlorite solution and incubating for 7 days. The results are given in Table 1.

The other aspect relates to the comment made by Larter (1974) concerning the poor results from feeding trials, which he attributed to the presence of ergot in the sample. Many fungi less conspicuous than ergot, especially storage fungi, e.g., *Aspergillus*, and species of *Fusarium* produce toxins. Some of these, e.g., Zearalenone produced by *F. graminearum* Schwabe *(Gibberella zeae* (Schw.) Petch), are oestrogenic and result in sterility, abortion, and unthriftiness in animals. *F. graminearum* is a common cereal pathogen and has been found on triticale at El Batan. It causes a foot rot with resultant whiteheads and purple superficial perithecia at the base of the culms, and a head blight, commonly known as scab. Affected ears produce large numbers of both perithecia and conidia.

Epidemiology and Disease Resistance

The true impact of a disease on a crop can only be observed when the crop is grown extensively under field conditions, thus permitting the development of natural epidemics. Large areas of triticales are present in only a few, scattered locations in the USA

TABLE 1. Seed-borne pathogens of triticale.

Seed stock	Source and harvest date	% infection		
		F. nivale	*D. sativa*	*F. 'roseum'*[a]
Armadillo 105		0	4	2
Armadillo PM 13		0	0	2
Cinnamon	El Batan Oct. 1972	0	11	2
Koala		10	0	0
Camel		0	11	0
Armadillo 105		0	0	0
Armadillo PM 13		0	0	0
Cinnamon	Obregon May 1973	0	0	0
Koala		0	0	0
Camel		0	0	0
Winter Triticale (Hungary)		0	0	2
Winter Triticale (F_4 S-6)	Toluca Aug. 1973	2	0	1
Winter Triticale (USSR)		1	0	2

[a]*F. 'roseum'* is a name used to include *F. culmorum*, *F. graminearum*, and *F. avenaceum*. It was not possible in the short period of our study to identify the species with certainty.

and Europe and the development of disease epidemics in these crops has not been studied. Disease observations on triticale have been very largely limited to small plots; diseases in these can be greatly influenced by inoculum produced outside the crop, whereas epidemics within large acreages depend mostly on inoculum generated within the crop. Inoculum production is an important criterion for assessing field resistance in small plot observation.

In some triticale diseases, sporulation of the pathogen is rather sparse, e.g., stripe rust *(Puccinia striiformis* Westend) and some *Septoria* diseases. "Slow rusting" and increasing adult plant resistance in some lines of triticale has been reported by Zillinsky (1973). These are manifestions of generalized or horizontal resistance that may be operable against all or most races of a particular pathogenic fungus, and it seems likely that such resistance may be present in triticale. Unfortunately, this type of resistance cannot be adequately selected for in small segregating populations without intensive "in depth" studies on mechanisms of infection and disease development. Nevertheless, the screening of all promising lines on a global scale in the international nurseries, and the inclusion of lines showing overall resistance in all areas in the general breeding program should ensure that some horizontal resistance is both detected and perpetuated.

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Agronomy and Physiology of Triticales

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Abstract The agronomic aspects of triticale have not been widely studied, although some unpublished data are available at CIMMYT. The limited work so far suggests that we should expect no important differences between the agronomic management of triticale and bread wheats of the same height. The effects of high soil N on the yield of triticale are discussed, as well as the desirable row spacing, seed depth, and time of planting to obtain maximum yield. Sink size, or the overall capacity of the grains to accept and store photosynthate, is discussed as a possible cause of shrivelling. Eliminating the basic genetic causes of shrivelling should lead to further yield improvement of triticale.

Résumé Les aspects agronomiques du triticale n'ont pas fait l'objet d'études étendues, bien qu'il existe à ce sujet au CIMMYT un certain nombre de données inédites. Les travaux limités effectués jusqu'ici laissent à penser que l'on ne doit pas s'attendre à des différences importantes entre les exigences culturales du triticale et des blés de même taille destinés à la panification. On traite des effets d'une teneur élevée des sols en N sur le rendement du triticale, aussi bien que de l'espacement souhaitable entre les rangs, de la profondeur et de l'époque du semis pour obtenir un rendement maximal. On évoque également la capacité d'accumulation des produits de photosynthèse comme cause possible du plissement des grains. L'élimination des causes génétiques fondamentales de ce plissement devrait amener par la suite une amélioration du rendement.

Agronomy

WHAT there is to say about triticale agronomy is rather inadequate. Firstly, relatively little has been published about this area; secondly, most of the little we have done at CIMMYT, which is unpublished, has involved now-superceded lines of triticale. On the other hand, however, and with one or two exceptions, I do not believe there are reasons to expect important differences between the agronomic management of triticales and that of bread wheats of the same height category. Of course, CIMMYT will continue to intensify agronomic research with the new lines coming forward, but we certainly do not need to wait for all the results to come before encouraging the commercial production of triticales in appropriate situations.

Presently Available Results

Unless otherwise mentioned, these refer to irrigated conditions at latitude 27°N in the winter cycle in northwestern Mexico. The nitrogen response in the older triticales, such as Armadillo, is very close to that of the old tall bread wheats (Fig. 1). Starting with very low soil N, for example in the case of the 1969–70 and 1972–73 experiments, maximum yield under hand harvesting is reached with about 200 kg/ha N given at seeding, after which lodging becomes serious and yields tend to decrease. We have shown by preventing lodging with mesh that lodging at anthesis can reduce yield up to 1.5 t/ha depending on its severity. This is the same for tall bread wheats. The only difference I have observed is that, other things being equal, the triticales will lodge less than the bread wheats and have a greater capacity to right themselves by bending at the stem nodes.

With the shorter triticales now approaching 100–110 cm under our conditions, we have seen that lodging resistance at high N has been improved and there is no doubt that the optimal N application for maximum levels of profit or maximum yield will increase and approach those recommended for the current bread wheat varieties. For this reason as well as another to be mentioned later, yield levels must increase.

When it comes to seeding rate and row spacing, the picture under our conditions is again similar to bread wheats. Trials with

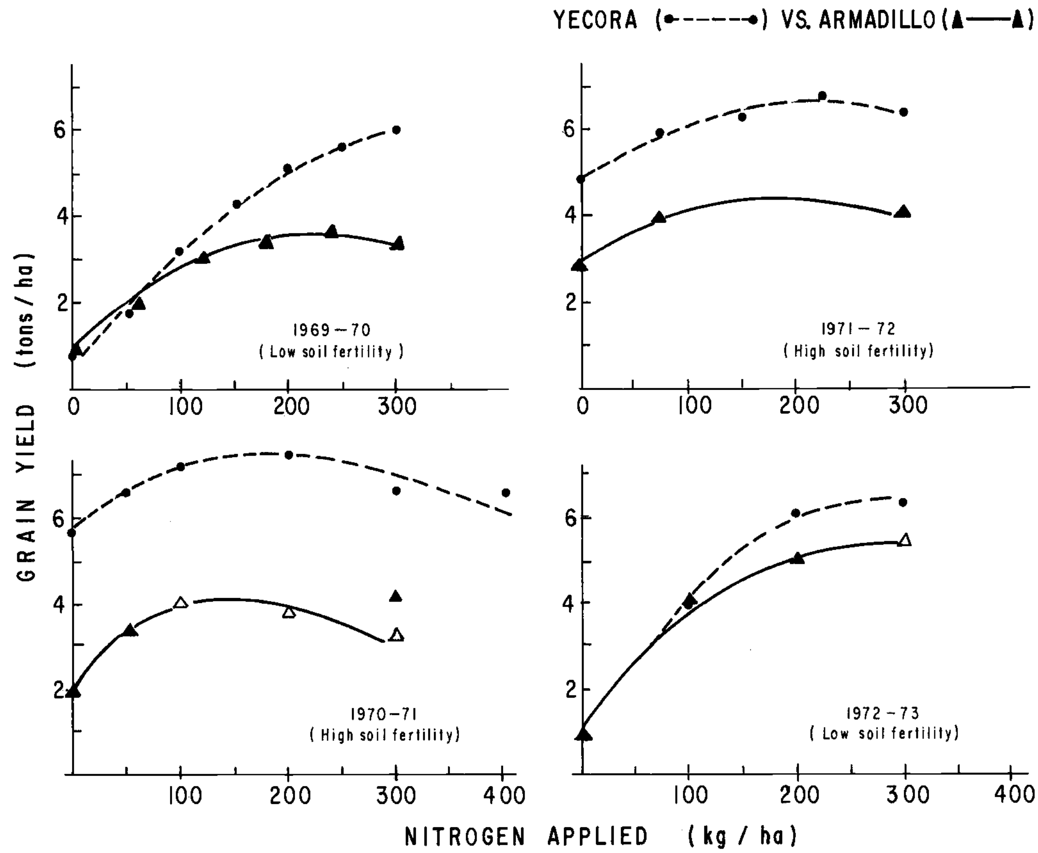

FIG. 1. Nitrogen fertilizer trials, using Yecora and Armadillo triticales.

Armadillo "S" show little response to density over the range 25–150 kg/ha (Table 1). This agrees with Larter and Kaltsikes (1971) who studied the triticale variety Rosner at Winnipeg. A recent study by the triticale section here in CIMMYT and using 10 triticales both old and new showed a 12% reduction in 60-cm row spacing compared with 30-cm row spacing. This is a relatively small reduction and taken along with the few other triticale results and numerous results from bread wheats suggests that a row spacing of up to 45 cm can be tolerated under our conditions without any loss in yield. Rows narrower than 30 cm would probably lead to greater lodging and no increase in yield. Thus unless drastic changes in plant type occur in the future, or weed problems are serious or seed bed preparation poor, I would predict that triticales in the irrigated low latitude environments will produce optimally at densities from 40 to 80 kg/ha and row spacings 20–45 cm.

In the seeding density trials, although increased seeding rate increased ear numbers somewhat, this component even at 150 kg/ha of seed (200 established plants/m^2) still remained noticeably inferior to the bread wheats. This and other studies with bread wheats suggest that increased seeding density will not rectify the supposed problem of low ear numbers observed in triticales.

TABLE 1. Effects of seeding density on grain yield of triticale (Arm "S" 105X-308-OY). Trial A VIII, CIANO, 1970–71; mean of planting systems.

Density *kg/ha*	Grain yield (12% moisture), *t/ha*
25	4.31
50	3.88
100	4.11
150	3.83
Diff. for significance 5%	0.48

Seeding Depth

In many dry-land situations it is important that seedlings can emerge from plantings at considerable depth, for example 10–12 cm. Triticale seedlings appear to be generally low in vigour and in one small trial in northwest Mexico last season the line Cinnamon "S" emerged satisfactorily only when sown no deeper than 9 cm, whereas two bread wheats and another triticale emerged well from 12 cm.

Optimal seeding date is rather a regional specific recommendation. In one trial last winter season in northwest Mexico, Cinnamon "S" was seeded along with three top bread wheat varieties and one top durum at five different dates from 26 October to 18 January. Best yields were obtained for all with December sowings but curiously the triticale showed greatest yields relative to the others with the late October and mid-November sowing (Fig. 2). The early sowings encountered warm conditions early, followed by cool cloudy conditions from jointing through maturity. The triticale showed its superiority especially in grains per ear. This contrasts with results from summer sowings in Canada (Larter and Kaltsikes 1971) where the triticale Rosner became relatively less well adapted with later seedings in the range mid-April to late May, an effect assumed to be related to the increased temperatures during the tillering period with later sowings.

The above Mexican results plus the relatively good performance of triticales observed in certain situations such as northwestern Mexico last season (a cloudy cool season compared with the normal), the summer plantings in central Mexico (always cool cloudy situations), and finally highland conditions in low latitudes (for example Ethiopia) provide sufficient evidence to advance the hypothesis that CIMMYT spring triticales are relatively better adapted to cool cloudy conditions than the Mexican spring wheats from which they have been derived.

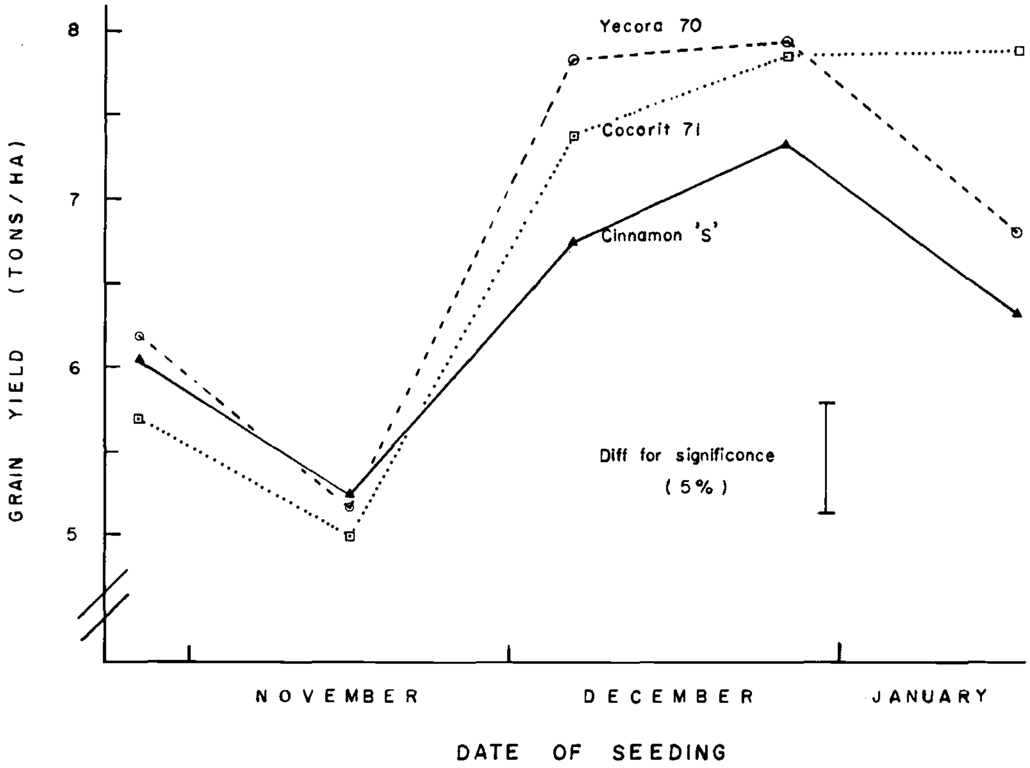

FIG. 2. Date of seeding trial, D II Y72-73.

Drought and Cold Resistance

Another hypothesis relevant to the adaptation and management of triticales is that being descendents of rye they are relatively resistant to drought, and also to cold. I have been unable to find any published evidence relating to this. Kaltsikes (1971) did show that the triticale Rosner was of intermediate yield stability compared to bread wheats and durums across 10 localities in Manitoba. At the outset I would caution that one can usefully recognize around the world three or four quite distinct types of drought faced by cereals, not to mention differences in severity within any type and modifying effects of soil texture and depth. Thus we have only studied the response of certain triticales to what I call simulated Mediterranean drought, involving terminal post-anthesis water stress. On the heavy soils in northwestern Mexico with moderate stresses so far we have found no evidence for greater drought resistance in triticales compared to bread wheats (Fig. 3). On checking some of the old literature on rye one gets the impression that the only mechanism for drought resistance in rye may be earliness, and that in fact rye is quite susceptible to drought and heat in the flowering and post-flowering periods.

Regarding cold resistance one must also recognize different situations when cold damages cereals, specifically winter-kill, for which winter rye has superior resistance, frost damage to elongating stem tissue, frost damage causing sterility of the spike and frosting of the ripening grains. There seems to be some evidence that spring triticales show unusually good winter-hardiness for spring cereals. Superior resistance to frost damage has not been reported to my limited knowledge and I am not sure that it is possessed by rye anyhow.

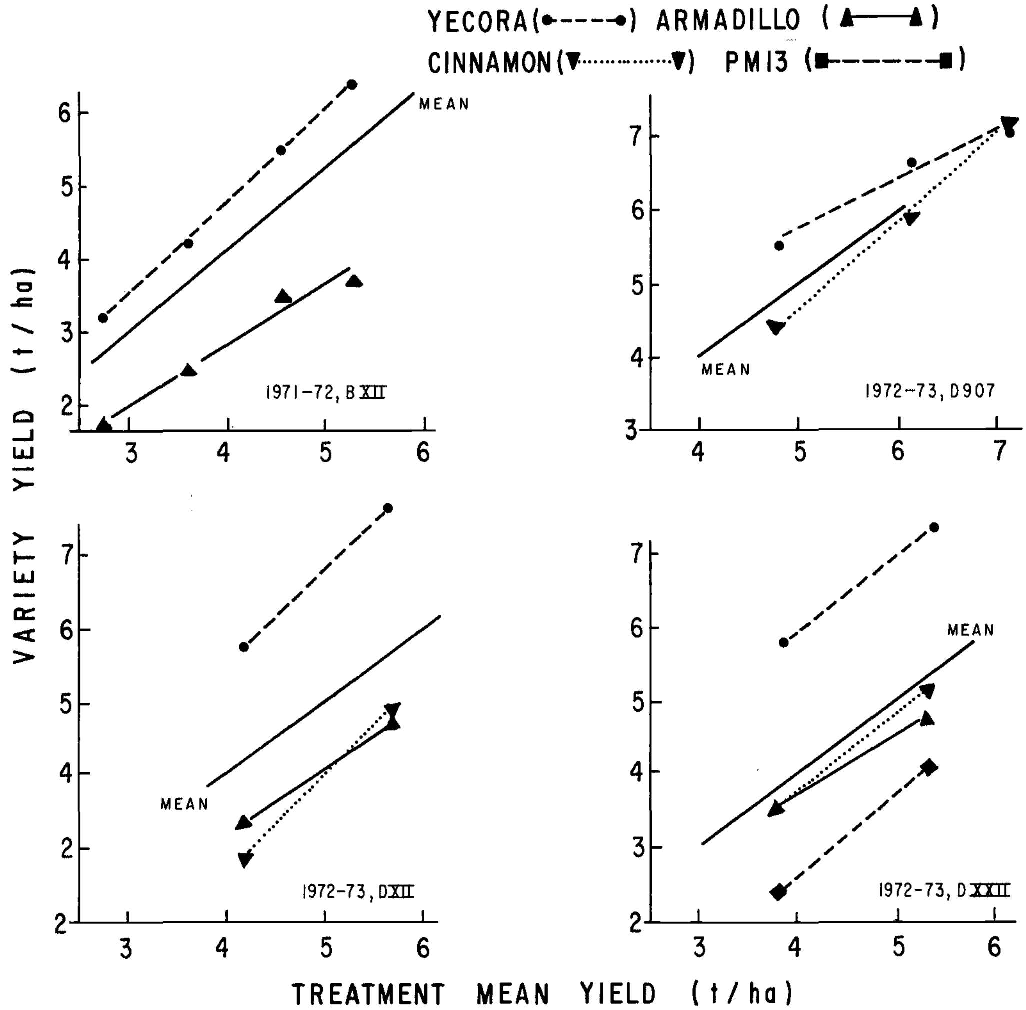

FIG. 3. Triticale water stress trials.

Agricultural Chemicals

Some care must be taken to see that triticales are tolerant of the agricultural chemicals being applied to them. Referring to herbicides, we have found triticales generally to be highly tolerant of dinitro and carbyne, more tolerant of 2,4-D than bread wheats, and reasonably tolerant of Tribunil, depending in the last instance to some extent on the environmental conditions. However, with a moderate dose of the common insecticide DDD-Toxaphene, applied 3 weeks after seedling emergence, in a set of 28 triticales only 5 showed no damage, while 18 showed moderate to severe damage, sufficient to reduce final yield; the same application to many durum and bread wheat lines caused no damage whatsoever. It is not known at the moment which was the toxic ingredient of this insecticide but serious toxicity has been observed in three successive seasons.

Physiology

Except for work on the nature of grain shrivelling, studies of the physiology of triticales are very few. As a corollary to our studies of the crop physiology of bread wheats certain key triticales have been included in most trials. These trials have been conducted under high-fertility irrigated conditions of the winter cycle in northwestern Mexico. Because of lodging of the taller older triticales and the frequent appearance of new improved strains, the results of these comparative studies are of rather limited value. Nevertheless, some points are worth mentioning.

Although the triticales studied tended to have slightly smaller leaf area indices, biomass production has always been close to that of bread wheats. The yield disadvantage of older triticales therefore clearly rested in their reduced harvest indices or ratio of grain to total dry weight. Improvement in the yield potential of triticales has involved a steady improvement in harvest index (Table 2). Extensive studies with bread wheats suggest that this improvement is partly related to the reduction in plant height and is expressed even in the absence of lodging (which, although it occurred in the trials shown in Table 2, was too late to affect yield). Specifically, in the Mexican bread wheats over the past 15 years or so, stature has been reduced from about 120 cm to 75 cm, and in the absence of lodging, harvest index rose from about 0.33 to 0.45 and grain yield rose correspondingly. Triticales appear to be only part way along this course, for they have yet to reach yield potentials and harvest indices of the best triple dwarf bread wheats. Table 3 shows a comparison of the highest yielding

TABLE 2. Improvement in yield and its components in spring triticales at CIMMYT. Trials D XXXI and D XI, Y72-73.

Parameter	Triticale Armadillo "S" (120 cm)	Triticale Cinnamon "S" (130 cm)	Triticale Mayall-Arm "S" (100 cm)	Bread wheat Yecora 70 (75 cm)	LSD 5%
Grain dry wt, g/m^2	481	512	562	585	43
Total dry wt, g/m^2	1440	1449	1415	1285	123
Harvest index	0.33	0.35	0.40	0.46	0.03
Spike/m^2	286	224	319	417	31
Spikelets/spike	21.2	25.0	23.3	18.2	2.4
Grains/spikelet	1.71	2.10	2.07	1.68	0.40
Wt/grain, *mg*	46.3	43.6	36.8	46.0	2.0
Grain no., *1000/m*^{2}	10.4	11.7	15.4	12.7	1.2
Lodging score, 0–100	47	66	30	0	–
Date 50% ear emergence	22 Feb.	28 Feb.	24 Feb.	25 Feb.	–

TABLE 3. Key yield parameters for a very high-yielding crop of triticale and two high-yielding semi-dwarf wheats. Trial D II, seeded 7 December 1972, Y72-73.

Parameter	Bread wheat Yecora 70	Bread wheat Cajeme 71	Triticale Cinnamon "S"	LSD 5%
Grain dry wt, g/m^2	698	724	605	58
Total dry wt, g/m^2	1550	1745	1580	130
Harvest index	0.45	0.42	0.38	0.02
Spikes/m^2	456	437	318	51
Spikelets/spike	18.6	20.1	21.4	1.3
Grains/spikelet	1.84	1.85	2.00	0.17
Dry wt/grain, *mg*	44.9	44.5	44.6	2.2
Grains no., *1000/m*^{2}	15.6	16.3	13.6	1.5
Lodging score, 0-100	0	11	83	–
Date of 50% ear emergence	4 Mar.	12 Mar.	28 Feb.	–

triticale crop I have studied with two triple dwarf bread wheat varieties.

Tennenhouse and Lacroix (1972) reported further evidence that an inverse relationship between height and yield potential operates in triticale just as in bread wheats. These authors studied the effect of two doses of CCC (2-chloroethyl trimethyl ammonium chloride) on Rosner triticale in the field at Winnipeg in the absence of lodging; control height was 95 cm; + 3 kg/ha CCC reduced height to 81 cm and increased yield over control by 4%; + 6 kg/ha CCC reduced height further to 75.5 cm and increased yield over control by 12%.

In summary, I see no reason why triticale will not soon reach the height, harvest index, and yield levels of the best short bread wheats. Spikelet fertility obstacles may, or in fact, have arisen, but this is an entirely independent problem of reproductive physiology, the solution of which is unrelated, I believe, to the problems of partitioning the limited amount of biomass of the crop. The intriguing question, of course, for both bread wheats and triticales is where do we go having once achieved harvest indices of 0.45 (grain/straw ratio of 1.2).

It is interesting to also observe briefly the numerical components of yield reported in Tables 2 and 3. In Table 3 the triticale is clearly inferior only in spike number; spike size and spikelet fertility tend to be better than for the bread wheats, although grain number per unit area still remains somewhat inferior. Table 2 also shows the deficiency in spike number of the triticales; however, for the highest yielding triticale the superiority in spike size and spikelet fertility is sufficient to give a very respectable grain number per square meter.

It is rather dangerous to predict areas of yield improvement from such observations of yield components, even if the observations were more extensive. With less caution, however, Sethi and Singh (1972), after studying a diverse set of 31 triticales, pointed to spikes per plant as the most fruitful area for yield increase because of its strong correlation with grain yield per plant. The study was conducted under spaced plant conditions and, I think, the results predictable and the conclusion quite misleading.

Low spike number per unit area has always been observed with triticales. Tillering in wheats generally increases with lateness; spring triticales in solid stand tiller consistently less than most bread wheats of the same maturity. However, the bread wheat Siete Cerros, amongst others, shows a similarly low tillering capacity. In bread wheats, in general, lower tillering is associated with higher tiller survival; again, triticales fall below the relationship, having tiller survival percentages of around 35% when bread wheats would be averaging 50%.

Spikelet number is related to the length of the period sowing to terminal spikelet formation and hence maturity class, and to the rate of primordia production at the shoot apex. Triticales from our observations here and the published results of Rawson (1971) apear to spend more time for a given maturity class in the pre-terminal spikelet stages and also have a greater rate of primordia production. Thus their ears have greater numbers of spikelets for given maturity classes compared to bread wheats. This character is not solely the result of less inter-shoot competition due to lower tillering although this may be a necessary condition in solid stand. Ear size may in fact be one of the most important unique features of triticales, since it represents a potential avenue for increasing sink size. Suffice to mention that up to 40 or more developed spikelets per spike have been measured in certain spring triticales, a number never observed to my knowledge in spring wheats.

A third feature is the problem of the fertility of triticale spikes. This problem, however, may have been overcome in the spring triticales such as Armadillo, Beaver, and Cinnamon, at least for certain environmental conditions. In terms of grains per spikelet, these triticales compare very favourably with some 40 or 50 wheat and durum genotypes we have studied over the last 3 years. Of course this may not be a very satisfactory basis of comparison and it would be better to have data on grains per perfect floret. I myself prefer to think in terms of grains per unit of dry matter built into the ear structure at anthesis; on this basis also the newer triticales are as good as the other wheats.

Finally we come to the post-anthesis period and the grain size and shrivelling question. By grain size I mean dry weight per grain. The photosynthetic system at the beginning of this period for the triticales that we have studied is different in that the flag leaf lamina tends to be smaller and the area of other green leaf lamina greater than in other wheats. The canopy appears more open, with a greater area of green leaf sheaths and exposed stem tissue. In northwestern Mexico last season, leaf lamina removal treatments were applied at anthesis to random shoots of Cinnamon "S" and of three wheat varieties (Hira, Yecora 70, and Cocorit 71). Flag lamina removal reduced yield per spike 15% in the triticale and an average of 18% in the other wheats; with the removal of all lamina, the reductions were 41 and 27%, respectively. Reductions in grain number and grain size were involved, with clear evidence that lamina removal lead to greater reductions in grain number in the triticale compared to the other wheats.

In an experiment involving extreme crop thinning at anthesis three seasons ago, we showed grain size in two triticales to increase 18% in response to thinning, which we feel simply permits more light interception and therefore more photosynthesis in the remaining shoots. The response to such thinning in some 30 wheat varieties ranged from +3% to +40%. This and the above-mentioned lamina removal studies suggest that grain size in triticales is responsive in both directions to manipulation of post-anthesis photosynthate supply, just as occurs in most other wheats we have studied. If this is the case, it indicates that the capacity of the photosynthate translocation system is probably not a limiting factor. Also, since triticale grains remained typically shrivelled under the above conditions and since this shrivelled grain does not resemble grain of bread wheats produced under conditions of photosynthate shortage (e.g., heavy shading), it is probably safe to conclude that triticale grain shrivelling is a problem internal to the grain and not a supply problem.

From extensive experience with certain key bread wheats, I must emphasize, however, that the above results obtained with change in photosynthate supply do not mean that photosynthate is the only or even the major post-anthesis factor limiting grain yield in triticales. Sink size or the overall capacity of the grains to accept and store photosynthate must be considered. In particular it is interesting to speculate whether grain shrivelling and the metabolic disorders within the grain that it reflects represent a limitation in storage capacity. Evidence against this is that triticale grain size and grain growth rates are quite respectable when compared to bread wheats, and that differences in grain size between lines does not appear to be associated with differences in the degree of grain shrivelling (Klassen et al. 1971).

Evidence to support the above speculation that shrivelling represents a sink or storage limitation could be the following observation. Over the seven replicated triticale advanced yield trials, conducted last cycle in northwestern Mexico and involving 146 separate entries, grain yield variation was highly significantly associated with variation in test weight, which can be accepted as a good indicator of the degree of grain shrivelling. The linear correlation coefficient was low ($r = 0.28$), indicating that many other factors, including experimental error, were involved. Nevertheless the slope of the relationship was estimated with reasonable precision, and indicated an increase in grain yield of 90 ± 50 kg/ha for each 1 kg/hl increase in test weight. These results are especially useful because the experimental sample was large and reasonably diverse, with yields ranging from 4100 to 8300 kg/ha and test weights from 62.5 to 75.1 kg/hl. I would conclude from the above discussion that shrivelling causes reduced grain yields because it represents a limitation in the grain's sink or storage capacity, and that eliminating the basic genetic causes of shrivelling should lead to further yield improvements.

Conclusions

In conclusion, I would speculate that we will soon have for irrigated conditions new triticales that are shorter (90–100 cm), still relatively low in ear number, but very superior in ear size, acceptable in spikelet fertility, and somewhat improved in grain size. In contrast, new bread wheats may well be shorter still (70 cm), with small erect leaves and many more smaller ears and smaller grains. Both crops will approach yield potentials of about 8–9 tons/ha under optimal conditions, and will require, if soil fertility is to be maintained, from 200 to 300 kg/ha of N. The triticales may yield slightly more protein per hectare than the bread wheats.

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Early Steps on Triticale Breeding at CIMMYT

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QUIÑONES, MARCO A. 1974. Early steps on triticale breeding at CIMMYT, p. 211–212. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop Res. Centre Monogr. IDRC–024e.

Abstract CIMMYT began its triticale breeding work in 1964, faced with overcoming such problems as daylength sensitivity, lodging, fertility, kernel weight, disease resistance, and developing a better plant type. These traits were gradually assembled through breeding. Efforts were then diverted to intercrossing triticales with both bread and durum wheats to broaden the germ plasm base. After genes influencing such traits as a desirable plant type along with high levels of fertility and better seed development were assembled in blocks, a breakthrough resulted and Armadillo and other lines were selected.

Résumé Lorsque le CIMMYT a commencé en 1964 à travailler à la sélection du triticale, il s'est heurté à un certain nombre de problèmes tels que la sensibilité nychtémérole, la verse, la fertilité, le poids du grain, la résistance aux maladies et la création d'un type végétal meilleur. Tous ces points ont été progressivement traités dans le cadre de la sélection. On s'est ensuite orienté vers le métissage triticale/blés de panification et blés durs afin d'augmenter le capital génétique. Une fois assemblés par blocs les gènes influant sur ces caractères et aboutissant aux types végétaux désirés, soit des types dotés d'une fertilité élevée et d'un meilleur développement des semences, la victoire était là et l'on a pu produire l'Armadillo et d'autres lignées intéressantes.

TRITICALE breeding work at CIMMYT got underway in 1964. However, during the crop season of 1962–63, there were some primary triticales grown at our CIANO Station, introduced by Dr C. B. Jenkins, then with the University of Manitoba. These triticale types were excessively tall, light-sensitive, and tillered profusely. Ing. R. Rodríguez made some crosses into bread wheats more as a scientific curiosity than with any specific reason in mind. During the next 2 years, and once it was established that our wheat nursery during the winter could also be used as a triticale nursery, we saw more and more of the breeding materials handled by the University of Manitoba. At that early stage, we were impressed by the tillering ability and ear length of these earlier triticales, and when the breeding materials were returned to Winnipeg, a sample from the best populations was selected and brought to Toluca to be screened under this new environment.

By this time, we had already decided that if we were to take the best from this new crop, we would have to find ways of overcoming daylength sensitivity, reduce height to avoid serious lodging problems, increase fertility and kernel weight, and better the plant type. The first season at Toluca showed that we would also need stripe rust resistance, since almost 100% of the lines were lost due to this disease.

Through breeding, various traits were assembled. Some daylength insensitivity was recovered from triticale crosses carrying some degree of light insensitivity. This, however, was not enough, but by then, some triticale–bread wheat crosses were advancing rather well, so earliness and light insensitivity were complemented to that present in triticales. Disease resistance was also accomplished rather quickly. This was expected due to the dominant behaviour of such genes in most instances.

We did not have the skills to produce raw materials at that time, and recognizing the need to broaden the germ plasm base, diverted our efforts to intercrossing triticales with both bread and durum wheats. Moreover, to enhance the potential for a wider genetic base, F_1 wheat crosses were used heavily as female parental material. Eventually this move proved highly rewarding to our efforts insofar as transferring to the newer triticales the genes for dwarfing, earliness, light insensitivity, and high fertility.

Some traits, such as a desirable plant type combined with high levels of fertility and better seed development, are genetically more complex to inherit and for some plant generations we did not see too much progress. It was only after genes influencing such traits were assembled in blocks that a breakthrough came and Armadillo and other lines were selected. Progress from that point onward is reported elsewhere in the proceedings.

Introduction of New Forms and Types from Wheat and Triticale

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RODRIGUEZ, ING. RICARDO. 1974. Introduction of new forms and types from wheat and triticale, p. 213–215. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Crossing wheat with triticale offers good possibilities of producing varieties that are resistant to rust, have a higher nutritive quality, and possess higher yield. Such crosses would benefit triticale through incorporation of the more desirable agronomic characteristics of improved wheat. Improved varieties of triticale would enhance prospects for wider commercial acceptance.

Résumé Le croisement du blé avec le triticale offre de bonnes chances de créer des variétés résistantes à la rouille, de qualité nutritive supérieure et à rendement plus élevé. Ces croisements seraient bénéfiques pour le triticale, grâce à l'incorporation des caractéristiques agronomiques les plus désirables des blés améliorés. La production de variétés de triticale meilleures augmenterait les chances d'une acceptation plus grande sur le plan commercial.

AT CIANO in the growing season 1962–63, crosses between Mexican dwarf bread wheats and triticale were made for the first time. At that time the purpose was to see whether it was possible to succeed in making such crosses, and at the same time, determine what could be obtained from crosses between the two cereals.

Later, in work carried out by CIMMYT toward the development of hybrid wheats, again wheat was crossed with triticale, with two main objectives: (1) to transfer the cytoplasmic male sterility mechanism and the restoration of fertility from wheat to triticale; (2) to attempt a transfer of the better capacity for cross pollination from triticale to wheat.

It is obvious that these two points are intimately related to the production of hybrid wheats and triticales. At present the crosses of wheat × triticale take place in a more general framework that encompasses two interesting fields of work: (1) the transfer of desired traits from wheat to triticale, such as the mechanism for sterility and fertility restoration, short straw, grain type, disease resistance, ramified heads, etc.; (2) the transfer of desirable characters from triticale to wheat, for instance, high number of spikelets per spike, high number of florets per spikelet, grain size, nutritional quality, disease resistance, etc.

The exchange in germ plasm between these two cereals may lead to plants with better production capacity and superior quality.

In crossing wheat with triticale, few seeds with low germination due to aneuploidy are obtained in the F_1 and F_2 generations, but in the process of selection in the following generations, one can obtain plants that are completely normal, having the phenotype of triticale, wheat, or a blend of the two parents involved in the cross.

Results

Triticale

In the development of male sterile triticales and the restores necessary for the production of hybrids in triticale, it has not yet been possible to obtain sterility and restoration as effective as has been realized in wheat, but nevertheless, some progress has been made in obtaining several lines with near total sterility and good plant development.

The following material represents triticales with cytoplasm of *Triticum timopheevi* having the best male sterility:

Random selections from bulk O × H
Armadillo "S"
X-308-6Y-2B-100Y-1B-100Y
Tcl (E_3)-Arm "S"
H 277.69-1Y-2B-5Y-101B-7Y-5B-15Y
Tcl (E_3)-Arm "S"
H 277.69-1Y-2B-5Y-101B-15Y

Regarding the triticales with the best partial fertility restoration, several lines are available derived from the crosses H530.70A and H261.71, both of which contain the cytoplasm of *T. timopheevi* and at least a part of the genes responsible for the fertility or restoration genes that are found in this species.

From the first crosses of wheat × triticale, realized in 1962–63, segregants were obtained that phenotypically resemble the triticale parents, but with earlier heading, a high degree of sterility, and shorter stature. In addition, we maintain a line derived from the cross P4160 × triticale and another from My64 × triticale, corresponding to this first group of crosses.

The possibility of transferring the dwarfism of wheat to triticale is also evident in F_2 populations of recently realized crosses. Crosses from wheat with Tom Thumb Dwarfism (40 cm height) with semi-dwarf triticale (90 cm height) result in the appearance of segregant plants with the characteristics of triticale and the height from the wheat parent. An example is the cross CMH72A. 614, whose parents are Tcl (E_3)-Arm "S" (mother), and Hua R (E_4)-Buitres "S"[3] (pollen parent).

Finally, attempts are made to transfer ramification of the head from wheat to triticale, and already a small group of lines is available showing the characteristics of triticale combined with a stable degree of ramification. It is possible that using a system of backcrosses with normal triticale and ramified wheat, we may be able to finally incorporate the full complement of genes conditioning ramification in wheat into the triticale germ plasm.

The triticales with stable ramification mentioned above are lines extracted from the cross H 625.71, whose parents are Armadillo "S" (normal triticale) and 11-22609 × H485.65 (wheat with unstable ramification).

The ramification of the wheat parent used in this cross is unstable, whereas the ramification of the lines segregating from this cross is of a small degree, but stable.

In several triticales, there exists a certain tendency to produce ramifications in the heads of several plants, but the plants showing this characteristic are highly sterile, and, apparently this ramification is unstable. At present attempts are made to make the crosses from which it can be determined whether it is possible to stabilize the ramification already present in triticale or barring that, to try to transfer the ramification of wheat into triticale.

Wheat

The crosses of wheat × triticale represent a useful tool for the triticale breeder that is equally useful to the wheat breeder. Thus we see lines segregating from wheat–triticale crosses, with a phenotype similar to wheat, but showing a higher number of grains per spikelet than the conventional wheat varieties. Similarly, it has been possible to select wheats with over 17% protein content. The octoploid triticale, derived from the cross Inia × Turkey, yields, when crossed again to Inia 66, plants looking like Inia 66, but with better resistance to *Puccinia recondita,* which gives us the perspective of the transfer with relative ease of various types of resistance from rye to wheat.

Conclusions

According to our observations, the crosses of wheat with triticale constitute a field of work that is highly interesting for the breeders of these two crops. In wheat they afford the possibility of incorporating resistence to rusts, a better nutritional quality, and increased grain yields. Triticale, in turn, can be much benefitted, especially by incorporation of the agronomic characteristics that have been highly improved from wheat, such as the ramification of the head and perhaps also the filling of the grain; this last trait has greatly limited development of triticale varieties with broad commercial acceptance.

Extending Adaptability and Sources of New Genetic Variability in Triticale

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Kohli, M. M. 1974. Extending adaptability and sources of new genetic variability in triticale, p. 217–226. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract This paper reviews the earlier CIMMYT work on adaptation of wheat varieties, and the ongoing research on breeding for wide adaptation in triticale. The program initially included production of new amphiploids, at the hexaploid and octoploid levels. Also semi-dwarf, light-insensitive wheats were crossed with rye and directly with triticale to develop these characteristics in the latter. With an unexpected hand from nature, through a cross with an unknown wheat, the highly fertile "Armadillo" lines were born. Efforts are continuing to further diversify the genetic variability of triticales.

Résumé Ce texte passe en revue les premiers travaux du CIMMYT sur les facultés d'adaptation des variétés de blé, ainsi que les recherches en cours sur la sélection, moyen d'élargissement de ces mêmes facultés chez le triticale. Le programme a d'abord comporté la production de nouveaux allopolyploïdes au niveau des hexaploïdes et des octoploïdes. On a également croisé des blés demi-nains insensibles à la lumière avec des seigles et directement avec des triticales afin de développer ces caractères chez ces derniers. L'intervention inattendue de la nature (croisement avec un blé inconnu), a donné naissance à la fertile lignée "Armadillo." Les travaux se poursuivent afin de diversifier encore la variabilité génétique des triticales.

That many strains of plants differ in their performance in different years and under different environmental conditions is well known to both farmers and plant breeders. Certain of these conditions are more adversely influenced by environmental change than others. Thus, certain strains have specific adaptation and others general adaptation. The phenomenon of genotype $\times$ environment interaction has been recognized for a very long time but it has been difficult to use this to man's advantage because of the complexity of the characters involved. Most of the studies have dealt with only one or two environmental variables such as temperature, day length, or such morphological characters as synchrony of tillering, close crown, winter hardiness, and others. These are all responsible in one way or another for wide adaptation but are only a small part of the infinite number of genes concerned in making a variety widely adapted.

At the First International Wheat Genetic Symposium held at Winnipeg, Manitoba,

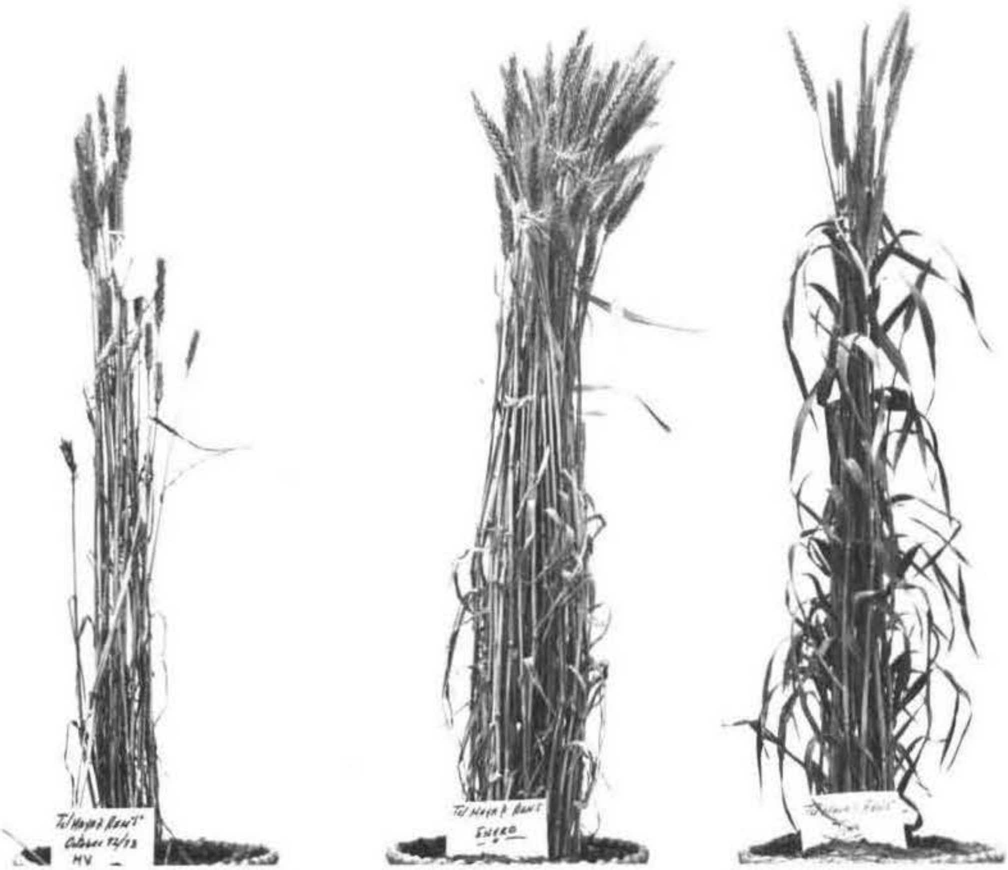

FIG. 1. Expression of plant type in a spring triticale line, Maya 11-Arm "S" under three dates of planting. *Left to right:* October, January, and May.

Canada, scientists had an opportunity to see a living herbarium grown for their benefit. The group of varieties from various countries included a few lines from an aggressive program on triticales, then in its early stages at the University of Manitoba. In 1965, varieties from this program were grown at the CIANO station in northern Mexico. They were nonadapted in the same way that many of the Canadian wheat varieties were nonadapted under the same conditions. Under Mexican conditions and indeed in latitudes below 35°, this material, being day length- or photoperiod-sensitive, cannot be grown commercially. The triticale material, in addition to being late, was very tall, susceptible to the prevalent diseases, highly sterile, and had badly shrivelled grain.

Photoperiod sensitivity was not the only factor involved. In previous experience with wheat, Borlaug (1972) observed a difference of 35% in yield depending on what time of year a variety was sown. This difference depended on whether the days were shorter or longer as the season advanced after emergence of the plant, in spite of having the same number of daylight hours. A similar response has been experienced with triticales at Toluca near Mexico City. Figure 1 shows the difference in plant development with October, January, and May plantings. Sown in October, when days are becoming pro-

FIG. 2. New variability in triticale. *Left to right:* winter triticale, winter × spring, and spring triticale.

gressively shorter during early growth, plant development is very poor and diseases and frost seriously attack the plants. Sown in May when day length is increasing in the early growth period, plants appear much healthier but are somewhat reduced in productivity during the heading to maturity period. The best results at this location are achieved with January planting when day length is increasing, the temperatures are cool during the early development, and the growth period spans the time of longest light periods.

In the CIMMYT wheat program varieties are being developed with a combination of high yield and wide adaptation. This result contrasts with the previously held view that only a specifically adapted genotype should be capable of very high yields in a particular environment. Finlay (1963) provided evidence from a study of combining ability that

FIG. 3. General pattern of segregation in triticale × wheat crosses.

the mean yield of a variety over a whole series of environments and yield stability, the two components of adaptation, were independent of one another. He suggested that this would certainly allow for combining high yield and broad adaptation. In the Mexican wheat program, breadth of adaptation is being achieved by alternately growing successive generations of hybrid material at Ciudad Obregon in the coastal plains of Sonora at 28° latitude and 40 m elevation and Toluca in the valley of Mexico at 18° latitude and 2600 m elevation. In the first-mentioned location much of Mexico's wheat crop is produced. Leaf and stem rust are principal diseases. The environment is typical of irrigated desert with bright sunny weather through most of the growing season. The second location, where virtually no commercial wheat is grown, is subject to excessive rainfall, cloudy conditions, and nearly all diseases of wheat. In both locations the short day-length periods ensure that all selected material must have day length insensitivity or are not long day-sensitive. Only those strains passing through this alternate screen successfully reach varietal status. Thus, selection for wide adaptation was an integral part of the breeding program. The same locations are used in triticale selection and the same types of material are being developed. In the studies by Finlay and co-workers, fixed homozygous varieties were compared to establish which had wide adaptation and which were specifically adapted to particular conditions. These they considered to be yield-stable and yield-unstable, respectively. The importance of Mexican varieties' yield stability through wide adaptation over many different ecological niches is exemplified by the spread of those classified as yield-stable over a broad geographic range in

TABLE 1. Triticale lines of II ITSN, chosen as superior by three or more cooperators.

Entry no.	Parentage	Holetta (Ethiopia)	Molo (Kenya)	Roode Plaat (S. Africa)	Palmerston (N. Zealand)	Quincy (Florida, USA)	F. Collins (Colorado, USA)	Tibaitata (Colombia)	Total
5	Armadillo "S"	*			*		*		3
9	Armadillo "S"	**			*		*		3
13	Armadillo "S"	**			*		*		3
14	Armadillo "S"	**			*		**		3
16	Armadillo "S"	**			*	*	*		4
17	Armadillo "S"	***			*				2
22	Armadillo "S"	***			*			*	3
24	Armadillo "S"			*	*			*	3
25	Armadillo "S"	*					*	*	3
28	Armadillo "S"	*		*			*	*	4
32	Armadillo "S"				*	*		*	3
38	Badger "S"				*	*		*	3
39	Badger "S"			*		*		*	3
40	Badger "S"			*		*		*	3
41	Badger "S"		*			*		*	3
42	Beaver "S" I			**	*			*	3
47	Beaver "S"	***	***	**					3
49	Beaver "S"		*	*		*			3
52	Bulk BV69 Selection C	*	*	**					3
55	UM "S"-Arm"S"				*	*		*	3
62	Kangaroo × MTE20-Per	*	*	**					3
63	Kangaroo × MTE20-Per	*	*	*			*		4

TABLE. 2. Results of the first, second, and third ITYN showing number of locations in which varieties appeared in top five in yield, the percent of locations, the number of times varieties outyielded the highest check (in case of check varieties, number of first positions indicated). Tests grown 1969–70, 1970–71, 1971–72.

	I ITYN 38 locations tested			II ITYN 17 locations tested			III ITYN 26 locations tested		
Lines or varieties	No. times variety among top 5	% locations	No. locations	No. times variety among top 5	% locations	No. locations	No. times variety among top 5	% locations	No. locations
ARM 102							7	26.9	1
104							7	26.9	2
105							8	30.8	3
107							6	23.1	3
108							4	15.4	1
109							2	7.7	2
111							8	30.8	4
112							7	26.9	3
113							5	19.2	2
114							2	7.7	–
116							2	7.7	–
117							1	3.8	–
130	5	13.2	–	2	11.8	–			
132							1	3.8	–
133	7	18.4	–	3	17.6	–			
136	15	39.5	–	6	35.3	1			
147	8	21.1	1						
157	4	10.5	–						
211	3	7.9	1	3	17.6	–			
1524	9	23.7	1	–	–	–			
PM 4				0	0	0			
PM 13				0	0	0	1	3.8	1

PPV 8				4	23.5	2			
PPV 13				6	35.3	1			
PPV 21				5	29.4	2			
T 909				8	47.1	2			
Badger									
118							5	19.2	4
119							6	23.1	4
121							3	11.5	1
122							6	23.1	3
123							6	23.1	3
Bronco									
PN 63							–	–	–
90	11	28.9	1	4	23.5	1			
Bruin									
34	1	2.6	–						
46	3	7.9	1						
Rosner	8	21.1	–	3	17.6	2			
UM 70-									
HN 470							2	7.7	1
PITIC 62	32	84.2	12	12	70.6	4	10[c]	40.0	7
INIA 66				9	52.9	6			
TOBARI 66	25	65.8	6				7[c]	28.0	1
ALBATROSS	20[a]	57.1	3						
JORI 69				8	47.0	1	7[c]	28.0	–
LOCAL	27[a]	79.4	10	10[b]	62.5	2	12	46.1	4
Grand	Unweighted	17.7%	0.0082		21.6%	0.0404		16.3%	0.0585
mean	Weighted	11.3%			13.8%			16.3%	

[a]Albatross in 35 tests and local in 34 tests.
[b]Local in 16 tests.
[c]Pi 62, Tob 66, and Jori 69 in 25 tests.

FIG. 4. Close-up of the type of plants resulting from triticale × wheat crosses.

countries of the subtropics of Asia and Africa.

As previously mentioned, wide adaptation and yield stability are influenced by many factors other than hours of light and temperature. There must be a wide range of genetic variability in the material under selection if the complex of genes for wide adaptation is to be brought together. Finlay (1971) considers that any type of adaptation can be isolated from a consideration of the yield scatter diagram developed for a variety over a group of environments, irrespective of type. Thus, those that respond to very favourable treatment could be used where weather conditions are predictable and inputs largely under the cultivator's control. Those unstable types could give great yields under conditions of good management. The stable types, however, are less affected by variations in the environment and yield relatively well over a wide range of conditions. With a very diverse gene pool, selection can be made that shifts the stable yield level upward in successive waves.

The Approach to Wide Adaptation in Triticale

In the foregoing, the general philosophy of breeding for wide adaptation has been discussed. With this background, Drs Zillinsky and Borlaug undertook to increase the genetic variability beyond that present in the Canadian material at the time CIMMYT began its collaborative program. New amphiploids were produced, both at the hexaploid and octoploid levels. Semi-dwarf light-insensitive wheat varieties were used in crosses with rye and directly with triticale to develop these characters in the triticale genetic background. At the same time nature took a hand and through a fortuitous cross of triticale by an unknown wheat, there arose several plants that were fertile, light-insensitive, and partially dwarfed. The lines, christened "Armadillo," provided fertility. This was so urgently needed for triticales as a whole that crosses were made with all other types to transfer fertility to them. Similarly with dwarfness, crosses were again made to transfer these genes throughout the general program. As better kernel types are found, a parallel process will undoubtedly be followed in placing this character across the range of genetic variability in the program. The net result of these activities has been a progressive narrowing of the germ plasm base. To offset this partial narrowing, expanded efforts have been made to develop many new amphiploids, use widely adapted wheat varieties in crosses, and incorporate new genes from the rye varieties. It appears from results of the International Triticale Yield Nursery (ITYN) and the International Triticale Screening Nursery (ITSN) supplied by cooperators of many countries that some of the varieties are still wide in adaptation.

During 1970–71, 70 triticale varieties were evaluated in the second ITSN. A listing of those varieties that were given excellent performance ratings at at least three locations is shown in Table 1. These have been again used for crossing to increase adaptability.

The results of three sets of ITYN trials are summarized in Table 2. At each location, the five top-yielding varieties were selected and compared for yield with the best wheat check. These results indicate a considerable variation in adaptation of individual lines. Some were widely adapted (high yield over many locations); others were adapted to very specific locations or showed poor adaptation at all centres. The weighted percentages for locations in which lines showed high yield have risen consistently (from 11.3 to 13.8 to 16.3%) from year to year. A similar but modest advance has also been made in the percentage of lines outyielding the highest wheat check variety included in the test (from 1% in the first ITYN to nearly 6% in the third). It is felt that as the major problems are solved wide diversity can be readily maintained in the triticale gene pool.

Sources of New Genetic Variability

At the Second International Barley Genetics Symposium, held at Pullman, Washington, Finlay (1971) stressed the importance of continuous infusion of new genetic variability in an active plant-breeding program. Failure to do so would lead to a narrowing of the genetic base to a point where very few varieties could be expected to emerge. Because of the forced narrowing of the triticale germ plasm outlined in the previous section, the group working on this crop are particularly aware of the danger. Every attempt is being followed to ensure diversity. Among these approaches are the following: (*a*) Winter-type triticales that have a vernalization requirement and carry a different germ plasm background have been received from Drs Muntzing (Sweden), Kiss (Hungary), Sanchez-Monge (Spain), Elliot (USA), and Qualset (USA). These can be grown during the winter months at Toluca. In the past season this material was screened and crosses effected between these and spring types grown in the nursery. Figure 2 illustrates some of the diverse plant characteristics shown by hybrids of the winter–spring program. Selections among these types could provide material suited to large areas of the Turkish, Iranian, Afghanian, and Algerian plateaux where varying degrees of winter hardiness are desired.

(*b*) During 1972 collections of rye varieties were made in the transition zone of Turkey. In addition, rye samples have been supplied by many European countries and Argentina and the USDA has kindly sent the world collection of ryes. The early triticales had a very narrow base insofar as the rye complement was concerned. Thus, crosses with this new set of rye varieties and development of new amphiploids involving this germ plasm will materially expand the variation of the rye portion of the triticale germ plasm.

(*c*) In the past two seasons activity has been intensified several fold in the production of new primary octoploid and hexaploid triticales. In this way the new gene combinations from diverse sources that have been available to the bread and durum wheat breeders will be successively introduced into the triticale background. Additionally, crosses are being constantly made between triticales and wheat and triticales and rye. Some of the diversity of types exhibited in segregates from these crosses is shown in Fig. 3 and 4.

(*d*) Modern techniques of anther and tissue culture and in vitro fertilization may be employed in developing new triticales. This could be of particular value in making those combinations that are otherwise difficult to produce.

In summary, continued efforts are being made to retain and further diversify the genetic variability of triticales, to provide the "soup" from which widely adapted varieties can be selected.

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Production of Triticale Germ Plasm

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GUSTAFSON, J. PERRY. 1974. Production of triticale germ plasm, p. 227–233. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Tremendous interest has been generated in the past 20 years in developing triticale as a commercial cereal crop. One of the limiting factors in reaching this goal, however, has been the narrow germ plasm base available to the breeder. We therefore studied various ways we could widen this base. The first method involved the synthesis of new amphidiploids. This approach is slow and labourious, involving complicated embryo culture and chromosome doubling techniques in a well-equipped laboratory. The second method utilizes standard field techniques, involving intercrossing various forms of triticale as well as the hybridization of triticales with tetraploid and hexaploid wheats, and diploid ryes. This latter approach is now being used in most breeding programs throughout the world, because it does not require the labour and expense of a laboratory procedure. Maximum exploitation of new germ plasm can only be obtained using both methods, however.

Résumé Depuis 20 ans, la mise au point du triticale en tant que culture céréalière commerciale fait l'objet d'un intérêt considérable. Dans la poursuite de cet objectif, l'un des facteurs limitatifs a cependant été jusqu'à présent la pénurie de matériel génétique disponible. Nous avons donc étudié différents moyens de pallier à cette insuffisance. La première méthode impliquait la synthèse de nouveaux amphidiploïdes. Cette méthode longue et laborieuse nécessite une culture d'embryons compliquée et l'emploi de techniques de doublage des chromosomes dans un laboratoire bien équipé. La seconde méthode utilise les techniques normales de sélection en plein champ par croisement de différentes formes de triticale et hybridation des triticales avec des blés tétraploïdes, ainsi que des seigles diploïdes. Cette méthode est maintenant employée dans la plupart des programmes de sélection à travers le monde, car elle n'exige ni la main-d'oeuvre spécialisée ni les frais des techniques de laboratoire. Toutefois, seul l'emploi des deux méthodes permet une exploitation maximale du matériel génétique nouveau.

A great deal of interest has been generated in the past 20 years in the production of various forms of triticale (× *Triticosecale* Wittmack) by combining various species of *Triticum* and *Secale*. Because the first triticale was reported less than 100 years ago (Wilson 1876), breeding programs are hampered by a lack of an adequate germ plasm base. One of the largest collections of primary amphiploids in North America is at the University of Manitoba and consists of approximately 500 amphiploids of both the 42- and 56-chromosome types. This is an extremely small germ base when compared to the USDA spring wheat collection of over 30,000 entries and durum collection of over 6000 entries. The need for expanding the germ plasm base of triticale is obvious and is receiving a high priority at the University of Manitoba. The purpose of this paper is to outline the various methods by which the germ plasm base can be expanded.

Production of New Amphiploids

Production of new amphiploids begins with the creation of the intergeneric hybrid, which involves crossing various forms of *Triticum turgidum* and *Triticum aestivum* with various species of *Secale*. Crosses between the hexaploid wheats and rye generally do not require embryo culturing as do the tetraploid wheat–rye crosses. If the embryos need to be cultured, culturing will take place between 14 and 20 days after fertilization depending on the particular cross involved. A summary of the embryo culture medium used at the University of Manitoba appears in Appendixes 1 and 2 and in Kaltsikes (1973). Some mediums can be obtained from commercial concerns.

The second stage in the production of new amphiploids is the doubling of the F_1 hybrid chromosome number. The methods of doubling chromosomes have been described in detail (Kaltsikes 1973) and will be mentioned only briefly in this paper.

The usual method of chromosome doubling involves treating the hybrid with the alkaloid colchicine. Several procedures have been used in the past and are summarized in Table 1. Many procedures have been tried at the University of Manitoba with none showing a clear advantage (E. N. Larter, unpublished data). There are surfactants, such as dimethyl sulfoxide (DSMO), alkyl ethoxylates, and nonylphenyl ethoxylates that appear to have the ability to act as carriers ensuring that the colchicine penetrates the cell (Klepper 1973). We are presently studying these and other chemicals.

TABLE 1. Procedures used in treating hybrids with colchicine.

Procedure	Reference
Seed treatment	Sears 1939
Crown method	Sears 1941
Capping method	Bell 1950
Injection method	Bell 1950
Schumann's method	Schumann 1960
Tiller method	Cauderon and Saigne 1961
Modified inversion or dropper method	Siddiqui 1971
Root immersion	Wellensiek 1947
Rutherford's method	Rutherford 1969

Nitrous oxide has also been used successfully to double the chromosome number of wheat (Kihara and Tsunewaki 1960), and barley and wheat, *Aegilops* hybrids (Dvorak et al. 1973). Our studies with this method are still inconclusive.

The above methods are all very inefficient in that few hybrids are produced and very few of those produced will ever get doubled. At the worst several hundreds of florets need to be pollinated to obtain a few F_1 hybrids to be doubled. H. Ono and E. N. Larter (unpublished data) have devised a method by which a stem of a hybrid once obtained can be cut into pieces and cultured resulting in the regeneration of hundreds of hybrid plants. This means that once a hybrid has been obtained it can be regenerated until such time as it is successfully doubled.

A third method proposed by Tsuchiya and Larter (1968) deals with doubling the chromosome number of parents and then crossing the doubled parents. They obtained a higher seed set by crossing the doubled parents over first crossing then doubling the resulting hybrid. Their main problem was that they had a very low rate of doubling the parents as compared to doubling the hybrids. We are not currently using this technique.

N. L. Darvey (unpublished data) proposed another method for increasing the gene pool of triticales, which involves crossing mixed autopolyploids or allopolyploids of wheat and ryes resulting in direct synthesis of triticales. This method is similar to the Tsuchiya and Larter (1968) method in that the parents need to have their chromosomes doubled before crossing can take place. The difference is that by being allopolyploids or mixed autopolyploids at the time of crossing both the wheats and the ryes will be highly heterozygous and an infinite number of triticale lines can be produced. From recent crosses involving eight heads of an allopolyploid timopheevi–durum hybrid with two accessions of autotetraploid rye cult Prolific and Fourex, a mean of 10.5 seeds per head was obtained. Twenty-six of the 84 seeds produced plants that are now being grown.

Utilization of Existing Material

The methods discussed in the previous section have dealt with the production of new germ plasm through the synthesis of new amphiploids. The production of new triticales is a long and involved process requiring laboratory facilities. The alternative methods proposed in this section will deal with techniques that can be utilized by a research program limited to a field operation. These methods deal with the introduction of genes from other species into triticale, the mixing of chromosomes from other species with those from triticale, and the combining of the genes from the old raw amphiploids that are no longer being utilized with those genes from the most current varieties.

56- × 42-Chromosome Triticales

One of the first methods of widening the germ plasm base in triticale is to intercross the 56-chromosome types with the 42-chromosome types (Pissarev 1963; Kiss 1966; F. J. Zillinsky, personal communication). This method not only allows the genomes that are in common to pair and recombine, but may permit the unpaired chromosomes to pair with their homologues. This is the only method where bread wheat, durum, and two varieties of rye chromosomes come together in the same cell at the same time and have the opportunity to recombine. Because there are breeding programs around the world (Russia, Sweden, and the People's Republic of China) that are dealing primarily with the 56-chromosome type of triticale, a great deal of untapped germ plasm is available for recombination with the more widely used 42-chromosome types. The resulting types could be just as important in yielding new germ plasm as making raw amphiploids.

Tetraploid Wheat × 42-Chromosome Triticale

In this method tetraploid wheat is crossed to 42-chromosome triticale with the resulting F_1 being backcrossed to 42-chromosome triticale. By doing this the two genomes of wheat present in the triticale are allowed to recombine with the tetraploid wheat. Tetraploid wheat would not be crossed with 56-chromosome triticale because there would be 14 univalents present in the F_1 that would severely reduce the chances of obtaining stable genotypes in one or two generations. The object, of course, of obtaining new germ plasm is to inject it into a breeding program as fast as possible. This method is being used in a few breeding programs throughout North America.

Diploid Rye × 42-or 56-Chromosome Triticale

By crossing diploid rye to either one of the two types of triticale and backcrossing the F_1 to the parent triticale the rye is allowed to recombine and become highly heterozygous as it is when in the natural state. As when raw amphiploids are produced the rye genome is in a homozygous state, which could be detrimental to the resulting triticale. If this is the case then making it heterozygous could be of great beneficial value. This method is currently being used by CIMMYT and the University of Manitoba.

Hexaploid Wheat × 42- or 56-Chromosome Triticale

The method of crossing hexaploid wheat with 42- and 56-chromosome triticale and backcrossing the F_1 to the triticale parent, or allowing the F_1 to self, is being carried out in several programs (Nakajima and Zennyozi 1966; Zillinsky and Borlaug 1971; J. P. Gustafson, unpublished data).

The crossing of hexaploid wheat with 56-chromosome triticale and backcrossing the F_1 to the triticale is exactly the same procedure as crossing tetraploid wheat to 42-chromosome triticale and is not used as widely as is crossing hexaploid wheat and 42-chromosome triticale. When hexaploid wheat is used as the female parent in the cross to 42-chromosome triticale it not only allows recombination between the wheat genomes, but results in a triticale with a hexaploid wheat cytoplasm. Larter and Hsam (1973) indicated that hexaploid wheat cytoplasm is advantageous when added to the 42-chromosome triticale. Not only are genes allowed to recombine, but whole chromosomes can be substituted when the F_1 is allowed to self resulting in desirable types (Gustafson and Zillinsky 1973; J. P. Gustafson and C. O. Qualset, unpublished data). This method allows the greatest chance for chromosome substitution to take place, and therefore is very important to a breeding program.

42-Chromosome Agrotriticum × 42-Chromosome Triticale

Currently we have a program underway to cross agrotriticums with the 42-chromosome triticales aimed at transferring the high lysine characteristic of the agrotriticums into a triticale background. This type of cross was done before by Zillinsky in Mexico and has resulted in a few lines selected at the University of California that have high lysine and a good triticale plant type. This method is of value because it points out that using wheat as a carrier makes it possible to transfer genes from widely diverse species into a triticale background.

42-Chromosome × 42-Chromosome Triticale

Recent work by Qualset and Gustafson (1973 unpublished data) has shown that a great many new genotypes are possible from crossing the old 42-chromosome types, which are not being used in many breeding programs, with the most recent types that have been coming out of the CIMMYT program. The older variety 6TA204 was just as good as the best wheats when compared on yield, whereas Rosner, T-1324, and T-122 were significantly lower in yield (Table 2). When Rosner, T-1324, and T-122 were compared to the wheats on seeds per spike, seeds per spikelet, and number of spikelets, they were very similar to the wheats, but when compared to the wheats on percent fertility they were significantly lower, which could be a partial cause of the yield differential. Variety

TABLE 2. Means of agronomic characters for four triticales and two wheats grown at Davis and Tulelake in 1970–71 (Qualset and Gustafson, unpublished data).

Variety	Seed source	Yield (*kg/ha*)	Seeds/ spike	Seeds/ spikelet	% fertility	No. spikelets
Triticales						
Rosner	Manitoba	3400 *d**	45.1 *c*	2.0 *a*	62.02 *c*	22.6 *b*
6TA204	Jenkins Foundation for Research	5400 *a*	66.8 *a*	2.2 *a*	71.58 *b*	30.6 *a*
T-1324	CIMMYT	4300 *c*	45.7 *c*	2.2 *a*	71.38 *b*	20.3 *c*
T-122	CIMMYT	4900 *b*	41.9 *c*	2.1 *a*	71.83 *b*	19.6 *c*
Wheats						
Siete Cerros 66 (hexaploid)		5800 *a*	50.0 *b*	2.8 *a*	80.63 *a*	17.7 *d*
Oviachic 65 (tetraploid)		5400 *a*	44.5 *c*	2.3 *a*	80.34 *a*	18.4 *d*
Best triticale as a % of best wheat		93	134	79	89	166

*Means followed by the same letter are not significantly different at the 5% level.

6TA204 was not significantly different from the wheats in seeds per spikelet and was significantly lower in percent fertility, but 6TA204 was significantly higher than the wheats in seeds per spike and number of spikelets by 34 and 66%, respectively. This means that 6TA204 had a much larger spike than either the wheats or triticales and was yielding as well as the wheats even though it was not as fertile. Although yield varies from station to station throughout California, 6TA204 maintained its spike size advantage over Siete Cerros 66 and maintained approximately the same level of fertility and seeds per spikelet (Table 3).

The CIMMYT line T-122 appeared to have a better tillering capacity and was shorter than any other triticale, which could account for the difference in yield between it and T-1324 and Rosner even though they were very similar in most other characteristics analyzed. If the tillering capacity and fertility of the CIMMYT lines could be combined with the spike length of 6TA204 and similar lines, a yield advantage would not be obtained for long, but new highly useful genotypes would be available. Recent observations of F_3 and F_4 populations of crosses made in California and Manitoba are beginning to indicate that such combinations can be made if large enough F_2 populations are grown in order to be able to pick out the recombinate types. A tremendous number of new genotypes can be obtained from crosses between older accessions and newer types, and the importance of maintaining germ plasm banks of all advanced breeding lines, both old and new, is very important at this stage in triticale breeding.

TABLE 3. The best triticale (6TA204) as a percent of the best wheat (Siete Cerros 66) at five locations over a 2-yr period for the agronomic characteristics analyzed (Qualset and Gustafson, unpublished data).

Location	Yield	Seeds/ spike	Seeds/ spikelet	% fertility	No. spikelets
Imperial Valley Field Station	100	147	76	82	144
Riverside	87	155	93	93	173
Westside Field Station	69	120	77	80	155
Davis	85	132	87	98	157
Tulelake	91	151	78	92	181
Mean	86	141	82	89	162

Screening Composite Populations

This technique could be valuable not so much for obtaining new genotypes, but as a method of obtaining large seeded lines of a higher test weight. The technique involves taking individual F_1 populations or composites of many crosses and by using a Carter Dockage Tester screening for large seeded types. The resulting large seeded types are then run over a gravity table selecting out the heaviest of the large seeded types. The resulting large-heavy F_2 seed is planted in a bulk population and harvested in bulk. The F_3 seed is handled in the same manner as the F_1 seed and again planted in bulk. This eliminates any environmental effect. Plant selections are then made from the F_3 bulk populations or composites and utilized in the same way as new lines.

Acknowledgments

I acknowledge financial assistance from the Canadian International Development Agency and the International Development Research Centre, Ottawa, Canada. I also thank Drs L. E. Evans and E. N. Larter for helpful criticism and suggestions, and Dr C. O. Qualset for permission to use unpublished data.

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Appendix 1

PREPARATION OF CULTURE MEDIUM FROM THE STOCK SOLUTIONS

To be used on large, well-formed embryos:

1. Add 60 ml deionized water to a 1500-ml flask;
2. add 200 ml stock solution A;
3. add 1 ml stock solution B;
4. add 1 ml stock solution C;
5. add 30 g sucrose;
6. add deionized water until a 1000-ml volume has been reached;
7. adjust pH to 5.9 using 0.1 *N* HCl or 0.1 *N* NaOH;
8. add 10 g agar and boil until dissolved;
9. pour into small vials and stopper;
10. autoclave for 20 min at 250°F at 1 atm and allow to cool.

To be used if embryos are small:

1. Steps 1, 2, 3, 4, and 5 are the same as above;
2. add deionized water until a volume of 965 ml has been reached;
3. adjust *p*H to 5.9 as above;
4. add 10 g of agar as above;
5. autoclave;
6. place in a 2000-ml sterilized separatory funnel;
7. add 5 ml sterile filtered stock solution D;
8. add 10 ml sterile filtered stock solution E;
9. add 20 ml sterile filtered stock solution F;
10. pour into small sterilized vials and allow to cool.

Appendix 2

EMBRYO CULTURE MEDIUM USED AT THE UNIVERSITY OF MANITOBA (MURASHIGE AND SKOOG 1962)

Stock solution	Ingredients		Concn in stock solution[a]	Final concn (*mg/litre*)
			g/litre	
A	Ammonium nitrate	NH_4NO_3	8.250	1650.0
	Potassium nitrate	KNO_3	9.500	1900.0
	Calcium chloride	$CaCl_2 \cdot 2H_2O$	2.200	440.0
	Magnesium sulphate	$MgSO_4$	0.850	170.0
	Potassium phosphate	KH_2PO_4	0.850	170.0
	Manganese sulphate	$MnSO_4 \cdot H_2O$	0.0845	16.9
	Zinc sulphate	$ZnSO_4 \cdot 7H_2O$	0.043	8.6
	Boric acid	H_3BO_3	0.031	6.2
			mg/250 ml	
B	Potassium iodide	KI	207.50	0.83
	Copper sulphate	$CuSO_4 \cdot 5H_2O$	6.25	0.025
	Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	62.50	0.25
	Calcium chloride	$CoCl_2 \cdot 6H_2O$	6.25	0.025
			mg/50 ml	
C	Iron sulphate[b]	$FeSO_4 \cdot 7H_2O$	1245.00	24.9
			mg/100 ml	
D	Indoloacetic acid		20.00	1.0
			mg/100 ml	
E	Kinetin		10.00	1.0
			mg/250 ml	
F	Glycine		25.00	2.0
	Nicotinic acid		6.25	0.5
	Pyriodoxine · HCl		6.25	0.5
	Thiamine · HCl		1.25	0.1

[a]Use deionized water only.

[b]Take 1.305 g EDTA + 10 ml H_2O add 13.4 ml 1 M KOH then shake and dissolve all the EDTA; pH should be 7.0 then add 1.245 g $FeSO_4 \cdot 7H_2O$ and bubble air overnight. After adjusting resulting solution to pH 5.2 add H_2O to a volume of 50 ml.

Broadening of the Triticale Germ Plasm Base by Primary Hexaploid Triticale Production

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CAMPOS VELA, ARMANDO. 1974. Broadening of the triticale germ plasm base by primary hexaploid triticale production, p. 235–236. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract Production of new primary hexaploid triticales that require embryo culture and colchicine treatment techniques different from those used to treat germinating seeds has been greatly increased by modifying existing methods. More than 2000 embryos were grown in the 1973 summer season, representing 260 new crosses of primary hexaploid triticales. This increase in available germ plasm will result in greater adaptability and yield potential.

Résumé La production de nouveaux triticales hexaploïdes primaires, que exige la culture d'embryons et l'emploi de techniques de traitement à la colchicine différentes de celles utilisées pour les semences en cours de germination, a augmenté considérablement grâce à la modification des techniques existantes. Plus de 2000 embryons ont été cultivés au cours de l'été 1973 et ils représentent 260 nouveaux croisements de triticales hexaploïdes primaires. Cet accroissement du stock génétique disponible se traduira par une augmentation des facultés d'adaptation et du potentiel de rendement.

THERE seems to be general agreement among triticale improvement scientists about the lack of genetic variability in the triticale program. This also has been recognized by the CIMMYT triticale program workers and due concern has been expressed.

Unfortunately several problems in the past prevented an earlier broadening of the germ plasm base of the triticale program.

Up to 1971, very few primary hexaploid triticales representing only a few crosses were available to the program. Thus, the excellent germ plasm available in the durum wheat program in CIMMYT had not been fully exploited.

At the same time, efforts were made to improve lodging resistance and yield through selection, which further narrowed the existing gene pool. This became very obvious during the 1969–71 yield trials in which the narrow range of yield suggested lack of genetic variability or at least the desirability of increasing the existing germ plasm.

The production of new primary hexaploid triticales that require embryo culture and colchicine treatment techniques different from those used to treat germinating seeds have been greatly increased.

The techniques used to grow excised embryos in complex nutrient media are similar to the methodology used in the Rosner Laboratory, University of Manitoba, Winnipeg, Man., Canada, with slight modifications, such as the use of ultrafiltration after the addition of kinetin and indoleacetic acid instead of waiting for the autoclaved medium to cool down, and then the addition of those materials under sterile conditions before filling the vials. This cumbersome technique gave us in the past a high percentage of contaminants since the medium, once in the vial, could not be autoclaved again, due to the heat-liable nature of the growth promoters and nucleotides.

Although the indoleacetic acid was dissolved in sterile water with the help of a few drops of ethanol, the root development still gave us erratic results even up to 10 ppm in the medium. A simple modification, such as the addition of a few drops of KOH, modified the pH of the solution to the extent that root development in our embryos is no longer a problem.

Development of Sterilization Techniques

One of the most important steps in sterile culture work is surface sterilization of the seeds and resterilization of embryos after excision.

The combination treatment of 70% ethanol dip plus a 3–5-min exposure to 2.6–3% sodium hypochlorite was satisfactory in this project; however, sodium seemed to inhibit to a certain degree the root and general development of the excised embryo, probably due to the ion chlorine. The simple substitution of sodium hypochlorite by calcium hypochlorite improved our recovery rate.

Another modification was necessary due to the fact that numerous crosses are made at Yaqui Valley, and embryo transfers and development of haploid plants coincide with the hot months of May and June; therefore, embryos have to be taken to Mexico City for further processing, but unfortunately most of our staff is still in Yaqui Valley at that time.

This problem was solved by holding the excised embryos in culture under 2°C temperature up to 21 days and then allowing them to grow at room temperature in Batan headquarters. This gives us a month before the first primary triticale is ready for transfer to peat pots.

Colchicine Treatment Modifications

Basically a 4-h treatment of 0.25% colchicine solution has proved to be quite effective in chromosome members in the haploid hybrids. The only modification made was in the method of application: we changed from the waxed paper tube, to the capillary glass tube, to the actual method, which consists of inserting the cut tiller into a dropper filled with the colchicine solution and allowing the colchicine to be absorbed by the plant tissue. This, we found, is a clean, fast, and satisfactory method, which gives us enough seed in three or four tillers, which we now hold as reserve seeds of primary hexaploid triticales.

For this summer season alone we have more than 2000 embryos growing, representing 260 new crosses of primary hexaploid triticales; 139 are crosses between durum varieties and advanced lines and *Secale cereale*, 113 are crosses between durum F_1 and *S. cereale*, and 8 are interspecific triticale.

From the spring cycle (Yaqui 72–73), we have already doubled with colchicine 40 different crosses, and many others are at the flowering stage after colchicine treatment.

We believe that through this increasing in germ plasm now available, faster progress will be possible, as genetic variability will result in greater adaptability and yield potential.

Nutritional Value of Triticales as High-Protein Feed for Poultry

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McGINNIS, JAMES. 1974. Nutritional value of triticales as high-protein feed for poultry, p. 237–240. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The crude protein content of triticales now being grown either commercially or in experimental programs can be markedly influenced by seeding date (fall versus spring) and by the amount of soil moisture. As well, the degree of shrivelling or test weight of triticales is influenced by seeding date and growing conditions.

Protein efficiency ratio values obtained for triticales in a modified chick assay procedure were generally higher than values obtained for cereal grains, such as normal corn and different wheats.

Triticale can be relied on to supply as much as 80% of the total protein in diets for laying hens without adversely affecting results obtained. Normally cereal grains furnish about 40% of the protein in laying diets. Also, the high protein contribution of triticales to diets for young chicks and broilers and for young turkeys can be effectively and economically used in meeting the protein requirements of this age and type of bird. The growing turkey after 16 wk of age can effectively utilize very high levels of triticale in growing diets when the lysine requirement is satisfied.

Résumé La teneur brute en protéine des triticales actuellement cultivés en grand ou dans des programmes expérimentaux peut être profondément marquée par la date de semis (automne/printemps) et par la teneur en eau du sol. De la même manière, le degré de ratatinage et le poids spécifique des triticales sont modifiés par les dates de semis et par les conditions de croissance.

Les valeurs du coefficient d'efficacité protidique des triticales, relevées au cours d'un essai spécial effectué sur poulet, se sont révélées en général plus élevées que celles des autres céréales telles que le maïs normal et les différents blés.

Le triticale peut sans inconvénient fournir jusqu'à 80% des protéines totales des rations des poules pondeuses. Normalement, les céréales fournissent environ 40% des protéines des rations de ces pondeuses. De la même manière, il est possible d'utiliser efficacement et économiquement les triticales à haute teneur en protéine pour satisfaire aux besoins en protéine des jeunes poulets, des poulets à griller et des jeunes dindons. Le dindon en croissance de plus de 16 semaines peut, lorsque ses besoins en lysine sont satisfaits, utiliser avec efficacité des rations de croissance à très forte teneur en triticale.

FROM a nutritional point of view, triticales now available for use in feeding trials differ from wheats and rye in several important respects. The protein content of many selections of triticale continues to be much higher than most wheats and rye. The carbohydrate content of triticale seed is less and it would appear that this is significantly related to the high degree of shrivelling still encountered in most triticale selections. This characteristic undoubtedly also increases the percentage of protein in triticale. When the amino acid composition of triticale is expressed as a percent of protein it is not markedly different from wheat, but lysine appears to be slightly increased. Triticales do not tend to have some of the adverse nutritional factors present in rye that depress growth and increase the response to an antibiotic supplement. Also, the characteristic that rye has that causes a very sticky type of feces is generally absent from triticales.

In the research program on nutritional value of triticales conducted at Washington State University, we have utilized triticales grown in the CIMMYT program in Mexico, triticales grown in the plant-breeding programs at Washington State University in the Department of Agronomy, and a limited number of triticale samples that have been grown commercially in the State of Washington. The results obtained in these studies are discussed under the following various headings.

Protein Content of Triticales and Factors Affecting Protein Levels

Approximately 100 different triticale selections were analyzed for protein content recently. Some of these selections were seeded in the fall and others in spring. Some were grown in widely different locations in the state and others under irrigation and without irrigation. The protein content of these triticales ranged from 14 to 21% on an as-is basis and the moisture content of most samples was generally approximately 8%. When the results were summarized and analyzed according to selection, location, seeding date, irrigation practice, etc., it was evident that the same selections seeded in the fall had lower protein content than the selections seeded in the spring. It was also observed that spring-seeded varieties grown under irrigation had lower protein than the same selections grown without irrigation. There were also important differences in seed type that were related to seeding dates and cultural practices. Fall-seeded varieties or selections and selections grown under irrigation tended to have much plumper seeds than spring-seeded selections and selections grown without irrigation.

Protein Efficiency Ratio Values for Triticales

Because of the high protein and high amino acid requirements of young chicks, the conventional protein efficiency ratio (PER) values obtained with rats or mice are relatively meaningless when obtained with chicks. Because of this, a modified assay was developed, and in this test all of the cereal grains supplied the same amount of supplementary protein in a diet that also contained protein from other sources. In this type of procedure triticales generally gave higher PER's than corn or wheat. Some triticale selections differed markedly in their PER values and this difference appears to be related to an unidentified factor that increases the need for an antibiotic supplement to the diet. Caution should be used in ascribing large differences in PER values to differences in protein quality or amino acid composition where data obtained by conventional biochemical determinations do not show large differences.

Feeding Value of Triticales for Different Types of Poultry

Because of the relatively high protein content of triticales, it is important to know how triticales can be used most effectively in practical poultry diets to make the most efficient use of the high protein contribution of triticales to the mixed feed. Experiments have been conducted with different types and ages of poultry to investigate the nutritional value of triticale as a component of mixed feeds.

Chick and Broiler Studies

Studies with young chicks and broilers found that the high protein content of triticales can be used effectively in meeting the total protein requirements of this type of bird when amino acid requirements, especially lysine, are adequately met. Based on growth and feed efficiency results from these studies, it would appear that the energy content of triticales is also efficiently utilized since the results were generally comparable to those obtained when corn was used as the grain component of the diet. The amount of high protein concentrates, such as soybean meal, could be reduced because of the extra protein supplied in the feed when triticale was used to replace other cereal grains.

Triticale for Laying Hens

Triticales of different types or origins have been used in a number of experiments with laying hens to test their nutritional values for this type of bird. The protein requirement of laying hens is indicated to be approximately 15% by the National Research Council Committee on Poultry Nutrition, but many practical feeds for layers are mixed to contain a protein level of 16–18%. Diets containing these higher levels were used in some of the studies and in others the experimental design was made to test the possibility of supplying the extra protein above 15% with triticale. The results of these studies show rather clearly that triticale as the only source of protein in a diet for laying hens will not support normal egg production. When low levels of protein concentrates, such as soybean meal or fishmeal, were used in combination with triticale to supply the total dietary protein, normal egg production was obtained. The reduced egg production obtained when triticale was used as the only source of protein appears to be related to an inadequate level of lysine and possibly to an inadequate amount of threonine.

The results of the studies with laying hens clearly show that important economies can be achieved in formulating feeds for laying hens through the use of high protein triticales to reduce the amount of more expensive protein concentrates such as soybean meal, fishmeal, and meat and bone meal.

Studies with Turkey Poults

One experiment was conducted with turkey poults to determine whether the protein contributed by triticale could be used effectively in meeting the high protein requirement of turkey poults. During the first several weeks of life, young turkeys are normally fed diets containing between 28 and 30% protein. To formulate a feed with this protein content, high levels of protein concentrates must be used. When triticale was used in this type of feed, and the protein level kept constant, the amount of soybean meal per ton was reduced about 300 lb. Growth and feed efficiency of turkey poults fed the diet with triticale were comparable with results obtained with the control diet containing corn and a higher level of soybean meal.

Studies with Growing Turkeys

A very important part of the total feed consumed by turkeys in reaching market age or weight is consumed after the turkey is 12–16 weeks of age. A study was conducted in 1972 to determine whether the protein of triticale could be effectively utilized in meeting the total protein needs of turkeys after 16 weeks of age and to obtain information on the level of lysine required for supplementing diets containing a high level of triticale. Results of this experiment showed that a major part of the protein needed by turkeys after they reach 16 weeks of age could be supplied from triticale. This was especially true when supplemental lysine was added to high triticale diets either in the form of synthetic amino acid or through protein concentrates high in lysine. Growth and feed efficiency on the high triticale diet were comparable with results obtained with a conventional diet based on corn and higher levels of protein concentrate when an adequate level of lysine was added to the triticale diet. These results indicate clearly that the triticale used in this study did not contain adverse nutritional factors, such as those contained in rye, as levels of triticale in excess of 85% of the diet were fed and excellent results were obtained.

Comparison of the Vole, Rat, and Mouse as Assay Animals in the Evaluation of Protein Quality[1]

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McDonald, B. E., and E. N. Larter. 1974. Comparison of the vole, rat, and mouse as assay animals in the evaluation of protein quality, p. 241–246. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The object of the present study was to assess the value of the meadow vole (*Microtus pennsylvanicus*) as an assay animal in the evaluation of the nutritional quality, in particular protein quality, of cereals. Weight gains and efficiency of protein utilization for growth (grams gain/grams protein consumed) were determined for the rat, mouse, and vole according to the procedures recommended for protein efficiency ratio (PER) determinations. Protein sources included: casein, soybean meal, wheat gluten, faba beans (*Vicia faba*), wheat, triticale, rye, and oats. Weight gains and protein indices for the vole bore no relationship to the protein quality of the test materials. By contrast, assays with the rat showed casein and soybean to be nutritionally superior to the cereals and the protein quality of wheat gluten and faba beans appreciably inferior to cereals. Assays with the mouse followed a similar pattern to those with the rat, although the mouse was less responsive to protein quality than the rat. The results of this study suggest the vole is of questionable value in the assessment of protein quality.

Résumé L'objet de la présente étude était de s'assurer de la valeur du campagnol (*Microtus pennsylvanicus*) en tant qu'animal de laboratoire pour l'estimation de la valeur nutritive des céréales, et notamment de leurs qualités protéiques. Nous avons déterminé les gains de poids et l'efficacité des protéines sur le plan croissance (grammes gain/grammes protéine consommes) pour le rat, la souris et le campagnol conformément aux méthodes recommandées pour la détermination du coefficient d'efficacité protidique (CEP). Nos sources de protéine comprenaient: caséine, tourteau de soja, gluten de blé, fèves *(Vicia faba)*, blé, triticale, seigle et avoine. Les gains de poids et les indices protéiques chez le campagnol n'avaient aucun rapport avec la qualité de la protéine des aliments testés. Par contre, avec le rat, la caséine et le soja se sont révélés nutritivement supérieurs aux céréales, et la qualité de la protéine du gluten du blé et de

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[1]The International Development Research Centre, Ottawa, Canada, is gratefully acknowledged for encouragement and support of the work reported in this paper.

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la fève s'est révélée incontestablement inférieure à celle des céréales. Les essais sur souris ont donné les mêmes résultats que pour le rat, bien que la souris réponde moins bien que le rat à la qualité de la protéine. Les résultats de cette étude laissent à penser que le campagnol est d'une valeur douteuse pour la détermination de la qualité des protéines.

UNTIL recently, plant breeders paid little attention to the nutritive quality of cereals, in spite of the fact that cereals contribute a major portion of the protein in the diets of many humans throughout the world. One of the primary reasons for the lack of attention to the biological value of protein in cereal breeding has been the lack of satisfactory methods for evaluating protein quality in segregating lines. Chemical analyses give no indication of the biological availability of the individual amino acids to animals. Klein et al. (1972) found that opaque-2 corn was not only higher in lysine than normal corn but the lysine was more available. Traditional methods for the evaluation of protein quality using the rat are impractical for the plant breeder because the assays require too much material, they are relatively time-consuming, and the cost is prohibitive. However, if cereals are to meet a much greater portion of the human needs for protein, as has been suggested by many of the world health organizations, relatively simple, direct methods of evaluating protein quality must be found.

The object of this study was to assess the meadow vole (*Microtus pennsylvanicus*) as an assay animal in the nutritional evaluation of cereals. The vole has been used in the nutritive evaluation of forages (Elliott 1963; Schillinger and Elliott 1966; Keys and van Soest 1970; Shenk et al. 1971) and although its use in the evaluation of cereals has been promoted, it has not been carefully compared with other species. The vole appeared to present several distinct advantages as an assay animal. Maximum growth per unit of protein consumed occurred at dietary protein levels between 4.5 and 7.2% (Shenk et al. 1970). In addition, growth rate and food intake were reported to be essentially linear for the first 10–14 days post-weaning (Shenk et al. 1970). The present study compared the meadow vole with the laboratory rat and the laboratory mouse in the assessment of protein quality by the standard growth assay.

Methods and Materials

Weanling mice and rats were purchased from a commercial supplier (Biobreeding Laboratories, Ottawa, Canada). Weanling voles came from our own colony, which was established with breeding stock from Dr F. C. Elliott, Michigan State University, East Lansing, Mich.

Experiment 1

All animals were randomly assigned, 10 per treatment group, to each dietary regimen. Eight different protein sources, four cereals and four other proteins (Table 1), were assayed with each species. Each protein source was incorporated into diets (Table 2) containing 10% protein (1.60% N) according to the formulations recommended for protein efficiency ratio (PER) assays (Campbell 1963). Four of the test materials (casein,

TABLE 1. Description of test materials in experiment 1.

Test material	Description
Triticale	var. Rosner
Wheat	var. Neepawa
Rye	var. Cougar
Oats	var. Russell
Casein	Vitamin Test, Nutritional Biochemicals Corp., Cleveland, Ohio, USA
Soybean meal	Feed grade, 44% protein
Wheat gluten	Vital gluten, Ogilvie Flour Mills, Winnipeg, Manitoba, Canada
Faba bean	*Vicia faba* cult minor

TABLE 2. Composition of diets.

Ingredient	Amount of ingredient (%) 10% protein (1.60% N) diets	7% protein (1.12% N) diets
Test material[a]	11–76	7–50
Carbohydrate[b]	4–69	23–66
Corn oil	10	2
Cellulose[c]	5	20
Vitamins[d]	1	2
Minerals (U.S.P. XIV)	4	–
Minerals (Salts W)	–	3

[a]Test material plus carbohydrate made up 80 and 73% of 10% protein and 7% protein diets, respectively.

[b]1:3, sucrose to starch.

[c]Alphacel, ICN Nutritional Biochemicals Corp., Cleveland, Ohio, USA.

[d]Vitamin Diet Fortification Mixture, ICN Nutritional Biochemicals Corp., Cleveland, Ohio, USA.

triticale, wheat, and rye) were also incorporated into diets formulated to provide 7% protein (1.12% N). The procedures followed with the rat were those recommended for PER determinations (Campbell 1963). Similar procedures were followed with the mouse and vole except the test period was 21 rather than 28 days. Weight gain and feed intake for each animal was recorded for the entire period and for the 6-day period day 3–9.

TABLE 3. Description of test materials in experiment 2.

Test material	Source	Chemical analysis: Nitrogen (%)	Lysine (g/16 g N)
Casein	Nutritional Biochemicals Corp., Cleveland, Ohio, USA	14.40	7.81
Wheat–4859	CIMMYT	1.88	2.64
Wheat–4860	CIMMYT	1.98	2.62
Triticale–4861	CIMMYT	2.54	2.99
Triticale–4862	CIMMYT	2.50	3.08
Triticale–4863	CIMMYT	2.73	3.06

Experiment 2

Procedures were similar to those of experiment 1 except the growth period was only 14 days for all species and only one dietary protein level (10%) was used. The test materials (Table 3) consisted of casein, three lines of triticale, and two lines of wheat.

Results and Discussion

Average daily weight gain, average daily feed intake, and protein indices for experiment 1 are summarized in Tables 4, 5, and 6.

TABLE 4. Average daily weight of rat, mouse, and vole (experiment 1).

Diet: Protein source	Protein level (%)	Average daily gain (g): Rat (days) 3–9	Rat 0–28	Mouse (days) 3–9	Mouse 0–21	Vole (days) 3–9	Vole 0–21
Casein	7	2.60[a]	2.60	0.56	0.37	0.34	0.17
Triticale	7	1.88	1.61	0.63	0.41	0.34	0.35
Wheat	7	1.07	1.14	0.39	0.40	0.45	0.30
Rye	7	0.98	0.93	0.35	0.34	0.58	0.29
Casein	10	2.47	3.64	0.69	0.62	0.56	0.30
Triticale	10	1.66	1.71	0.54	0.40	0.51	0.38
Wheat	10	0.92	1.11	0.33	0.40	0.49	0.24
Rye	10	1.18	1.52	0.38	0.36	0.39	0.30
Soybean	10	3.00	3.09	0.70	0.63	0.49	0.33
Oats	10	1.67	2.40	0.35	0.27	0.38	0.27
Wheat gluten	10	0.37	0.22	0.12	0.09	0.37	0.18
Faba bean	10	0.36	0.26	0.08	0.17	0.38	0.20

[a]Mean for 10 animals.

TABLE 5. Average daily feed intake for rat, mouse, and vole (experiment 1).

Diet		Average daily feed intake (g)					
		Rat (days)		Mouse (days)		Vole (days)	
Protein source	Protein level (%)	3–9	0–28	3–9	0–21	3–9	0–21
Casein	7	12.9[a]	16.2	4.3	4.6	3.7	3.7
Triticale	7	12.9	15.0	4.5	4.8	3.9	4.2
Wheat	7	11.7	12.3	4.7	5.0	4.2	4.1
Rye	7	12.0	13.7	4.0	4.4	4.4	4.1
Casein	10	10.7	14.0	3.8	4.7	3.4	3.3
Triticale	10	11.3	13.2	3.9	4.0	3.2	3.2
Wheat	10	8.9	9.9	3.9	3.8	2.9	3.0
Rye	10	10.8	12.5	3.6	3.7	3.0	3.2
Soybean	10	11.9	14.0	4.2	4.4	3.8	3.4
Oats	10	11.2	14.9	3.2	3.2	3.6	3.2
Wheat gluten	10	8.1	8.7	3.0	2.9	2.7	2.6
Faba bean	10	8.8	9.2	3.6	3.3	3.3	3.0

[a]Mean for 10 animals.

Weight gains and protein indices for the rat (Tables 4 and 6) ranked the test materials in a predictable manner; performance was highest with casein and soybean and lowest with wheat gluten (deficient in lysine) and faba bean (deficient in methionine). In general, the same order of ranking prevailed with the rat whether determined on the basis of a 6-day or 28-day assay. However, coefficients of variation within dietary treatments were higher for the 6-day assay. Although the ratio of energy to protein in the diets providing 7% protein was similar to that of the 10% protein diets and the rat adjusted for the lower calorie density in the 7% diet by increasing food intake (Table 5), growth performance and protein indices were lower on the 7% protein diet than the 10% protein diet, especially for casein. Nevertheless, protein indices were appreciably higher for casein than for the other test materials, except soybean meal, regardless of dietary protein level.

Assays with the mouse tended to coincide with those of the rat when the test diets contained 10% protein. Growth performance (Table 4) and protein indices (Table 6) were highest for casein and soybean and lowest with wheat gluten and faba beans. Differences among the test materials were much less pronounced with the mouse than the rat. Weight gains and protein indices for the mouse were lower with casein and soybean and higher with wheat gluten and faba bean relative to the cereals than for the rat. Agreement between the 6-day and 21-day

TABLE 6. Indices of protein quality for rat, mouse, and vole (experiment 1).

Diet		Protein index (g gain/g protein consumed)					
		Rat (days)		Mouse (days)		Vole (days)	
Protein source	Protein level (%)	3–9	0–28	3–9	0–21	3–9	0–21
Casein	7	2.53[a]	2.20	1.80	1.08	1.08	0.60
Triticale	7	1.87	1.48	2.00	1.17	1.22	1.14
Wheat	7	1.23	1.28	1.24	1.14	1.42	0.99
Rye	7	1.12	1.01	1.29	1.14	2.02	1.05
Casein	10	2.16	2.52	1.74	1.32	1.63	0.91
Triticale	10	1.28	1.30	1.41	1.02	1.62	1.23
Wheat	10	0.83	1.11	0.88	1.08	1.64	0.74
Rye	10	1.03	1.28	1.16	1.03	1.31	1.01
Soybean	10	2.40	2.12	1.69	1.37	1.40	0.94
Oats	10	1.54	1.76	1.19	0.93	1.11	0.84
Wheat gluten	10	0.41	0.25	0.37	0.31	1.26	0.64
Faba bean	10	0.34	0.26	0.41	0.32	1.19	0.69

[a]Mean for 10 animals.

assays was much poorer for the mouse than the rat. Reducing the protein content of the diet adversely affected performance of the mouse much more than the rat, in spite of the fact that the mouse, like the rat, adjusted feed intake (Table 5) for the lower calorie density in the 7% protein diets.

Weight gains and protein indices for the vole (Tables 4 and 6) bore little relationship to either the rat or mouse. There was no indication that source or level of protein had any effect on growth performance of the vole. Most striking in this regard was the poor performance on the casein and soybean meal diets relative to that on the cereals and the relatively satisfactory growth on low-quality proteins such as wheat gluten and faba bean. Average daily weight gains and protein indices for the vole were significantly higher ($P < 0.05$) for the 6-day than the 21-day

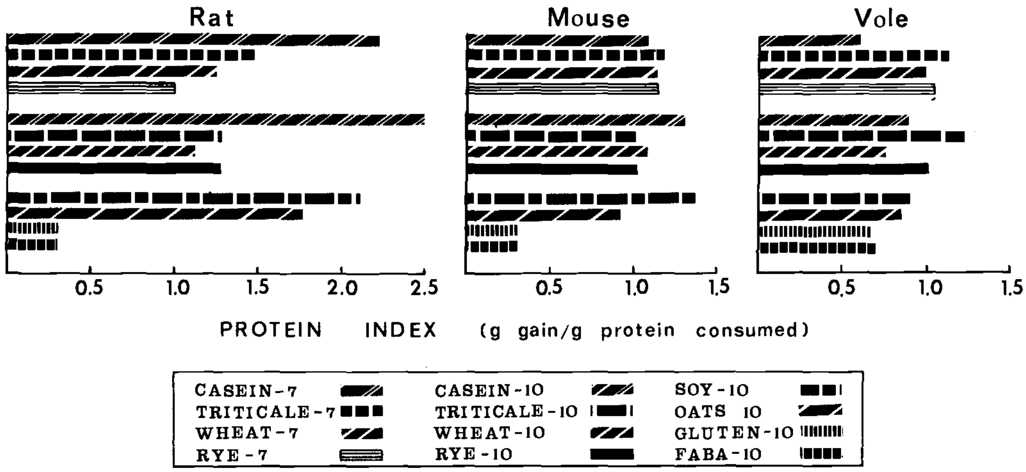

FIG. 1. Protein indices (*g body weight gain/g protein consumed*) with rat, mouse, and vole fed diets containing 7 or 10% protein from triticale, wheat, rye, oats, casein, soybean meal, wheat gluten, and faba beans (experiment 1).

TABLE 7. Biological evaluation of triticale an wheat using rat, mouse, and vole as assay animal.

	Rat			Mouse			Vole		
Diet	Daily gain(*g*)	Feed intake (*g*)	Protein index[a]	Daily gain(*g*)	Feed intake (*g*)	Protein index	Daily gain (*g*)	Feed intake (*g*)	Protein index
Casein	4.36[b]	17.4	2.28	0.89[c]	5.3	1.54	0.39[d]	2.7	1.37
Triticale 4863	3.01	16.9	1.66	0.85	5.6	1.40	0.42	2.5	1.53
Triticale 4862	3.24	17.3	1.71	0.78	5.8	1.25	0.57	3.23	1.59
Triticale 4861	3.06	21.1	1.62	0.71	5.4	1.22	0.58	3.08	1.76
Wheat 4859	2.23	17.8	1.32	0.70	5.3	1.26	0.57	3.0	1.82
Wheat 4860	2.41	16.2	1.36	0.73	5.6	1.19	0.59	3.3	1.64

[a]Grams body weight gain per gram protein consumed during 14-day test period.
[b]Mean for eight rats.
[c]Mean for 10 mice.
[d]Mean for 10 voles.

assay. However, neither the 6-day nor 21-day vole assays correlated with the 6-day or 28-day rat assays.

The marked differences in response to protein quality between the rat, mouse, and vole are illustrated in Fig. 1. The rat was very responsive to protein quality whereas efficiency of protein utilization for growth by the vole bore no obvious relationship to the protein quality of the test materials. The mouse tended to be intermediate between the rat and vole with the most striking difference from the rat being the less efficient utilization of casein and soybean meal relative to the cereals.

Essentially the same patterns were observed in experiment 2 (Table 7; Fig. 2). Weight gain and protein indices with the vole again were poor for casein relative to the cereals. On the other hand, weight gain and efficiency of protein utilization by the rat were considerably higher for casein than for the cereals. Performance for the rat also tended to be higher with triticale than wheat, which corresponds to the slightly higher lysine content in the triticale samples (Table 3). Again as in experiment 1, assays with the mouse followed the same relative pattern as assays with the rat, although in general the mouse was less responsive to protein quality than the rat.

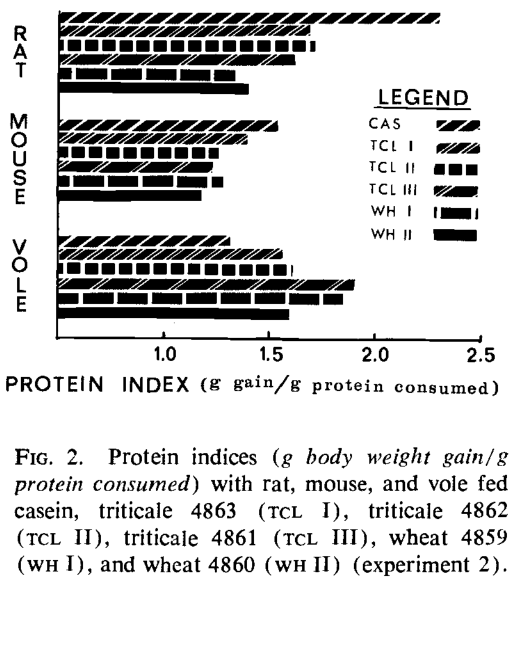

FIG. 2. Protein indices (*g body weight gain/g protein consumed*) with rat, mouse, and vole fed casein, triticale 4863 (TCL I), triticale 4862 (TCL II), triticale 4861 (TCL III), wheat 4859 (WH I), and wheat 4860 (WH II) (experiment 2).

The results of this study suggest that the meadow vole is of questionable value as an assay animal in assessing the nutritional quality, in particular protein quality, of cereals. The vole did not respond to the protein quality of a variety of test materials, whereas the rat ranked the test materials according to generally accepted standards of protein quality. Assays with the mouse followed the same general pattern as those for the rat, although the mouse was less responsive to protein quality than the rat.

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Future Role of Triticales in Agriculture

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SHEBESKI, L. H. 1974. Future role of triticales in agriculture, p. 247–250. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract A major milestone in the improvement of triticale occurred in 1964 when Dr Borlaug launched the triticale program at CIMMYT. The speed with which many of the difficult problems connected with the first triticales were at least partially resolved has been very impressive. The improvement in both fertility and seed density, and the broadening of the genic base have led to a rapid increase in yields. Triticale yields at CIANO, Tulelake, California, and Winnipeg, Manitoba, in 1973 were greater than the top wheats grown in these areas. Over the next 15 years, yields of triticale will improve much more rapidly than those of wheat and should plateau at a level approximately 50% higher than those of wheat. At that time, triticale will have begun to seriously compete with the bread wheats as one of the world's most important food crops.

Résumé L'amélioration du triticale a progressé à pas de géants depuis qu'en 1964 Monsieur Borlaug a lancé au CIMMYT le programme sur le triticale. Il est impressionnant de constater la rapidité avec laquelle un grand nombre des problèmes difficiles inhérents aux premiers triticales ont été au moins partiellement résolus. L'amélioration tant de la fertilité que de la densité des épis, accompagnée d'un élargissement des bases génétiques, se sont traduits par une augmentation rapide des rendements. Les rendements pour 1973 du triticale du CIANO, à Tulelake, en Californie, ainsi qu'à Winnipeg, au Manitoba, ont été supérieurs à ceux des meilleurs blés cultivés dans ces régions. Au cours des 15 années à venir, les rendements des triticales augmenteront beaucoup plus rapidement que ceux du blé et devraient se stabiliser à un niveau supérieur d'environ 50% aux rendements du blé. Le triticale aura alors commencé à rivaliser très sérieusement avec les blés panifiables en tant que l'une des cultures vivrières les plus importantes du monde.

WHEN I received the invitation to attend this symposium and to provide the concluding paper on the topic "The Future Role of Triticales in Agriculture," my better judgement told me that I should not accept. Having seen the imposing list of invited speakers — experts actively working on the improvement of triticale — I knew full well that, collectively, they would thoroughly cover all aspects of triticale synthesis and improvement, from the historical beginnings to an optimistic future and that there would be little left to say.

The excellent addresses and discussions we have listened to have confirmed my earlier convictions. Most speakers, while recognizing inherent weaknesses within the new species, were highly optimistic about its future. The collective optimism was probably best expressed by Dr Finlay when he said something to the effect that in the last 10 years the triticale species has made up for at least 20,000 evolutionary years of the 30,000 years of evolution experienced by the bread wheats.

Nevertheless, I accepted the invitation to speak, not because I could add anything new, but selfishly to hear of all the exciting things that were going on. If today I am to speculate on the future role of triticale in agriculture, I would like to do so largely on the basis of my personal experiences with the crop during the last 19 years and to supplement this with what I have heard or read. A look at the future is most safely made if based on past experience, and thus a brief historical review is called for.

It was only 19 years ago that I saw for the first time the hexaploid triticale. In 1954 we had obtained sufficient seed from Dr O'Mara to plant a single 5-ft row of the ABR combination in our wheat introduction nursery. I still vividly recall seeing the new species shortly after it headed and flowered. The vegetative vigor and the large spikes of the triticale were most impressive, and far outshadowed in appearance the surrounding well-adapted bread wheats and durums. It required very little imagination to visualize in this species a potential new cereal crop that could be far more productive than the bread wheats.

Coincident with our growing the hexaploid species for the first time was the establishment of the Rosner Research Chair in our Faculty by the Samuel and Saidye Bronfman Family Foundation, which made it possible to initiate the triticale program at the University of Manitoba, first under the direction of Dr Jenkins, and subsequently so ably carried on by Dr Larter.

I also recall showing that first 5-ft row of triticale to the late Dr W. J. Parker, President of the Manitoba Pool Elevators, and within a week had from him a pledge of $5000.00 per year for 4 years to provide support for the triticale program that was to be initiated by the Rosner Research Chair.

By 1958 we had developed a small collection of hexaploid triticale, some of which were introduced from Japan and the USSR, and others that were synthesized at Winnipeg. In addition we had a modest collection of the *Triticum* and *Aegilops* species that were believed to be the component species of the bread wheats as well as synthesized ABD's. These were all on display for the First International Wheat Genetics Symposium.

There were two things I believed to be strikingly clear in the field display prepared for that symposium: (1) that the synthesized ABR's were far more vigorous than either of the component parent species; and (2) that the synthesized ABD's or bread wheats, although more vigorous than the *Aegilops squarrosa* parent, were far less vigorous than their tetraploid *Triticum* parents.

This led to the natural conclusion that the D genome was a poor combiner with the tetraploid wheats for productive capacity whereas the R genome was a good combiner.

I had the privilege at that symposium to speculate on the impact of the D genome, and for those of you who were not there, I would like to recall the speculations made 15 years ago with excerpts from my paper:

> "If in the course of evolution — a genome other than the D had combined with the A and B — would the pattern of man's long struggle to provide adequate sustenance have been the same."

Quoting further, and admittedly out of context:

> "The ABR combination is particularly impressive and as a potential crop has all the appearances of being a far more productive starch producing plant factory than the best of the present-day bread wheats. Those of you who were on the field tour on Tuesday, I am sure will agree, that this species conveys such an impression. But we all know how deceiving visual impressions may be. Will there not be a good deal of sterility? Will not grain be badly shrivelled? Will the grain produced be of poor quality?
>
> "These questions were answered in part this morning by Dr Riley and Dr Sanchez-Monge — and the answers were not en-

couraging. But are we to forget that in the last 50 years scientists working on the improvement of the bread wheats have virtually doubled its yielding ability in many parts of the world? Are we going to put mental stumbling blocks before us and enter the field of directing evolution to our use too slowly — too cautiously?

"We recognize in the bread wheats that there are genic differences and certainly by breeding attempt to obtain better genic combinations. We recognize that there are chromosomal differences and can become quite enthusiastic about chromosome substitution — even chromosome substitution from different species. But if we can replace one of the chromosomes of the bread wheats by a chromosome from rye — are we not entering the field of genome construction? Should it not then be feasible to replace one of the rye chromosomes by a chromosome from the D genome and improve the seed shrivelling characteristics without losing too much of the phenomenal vegetative vigor?"

The questions raised 15 years ago were certainly well covered and answered during the past 3 days.

Yield trials carried out with primary synthesized hexaploid triticales were disappointingly low and did not live up to their vegetative potential, for the obvious reasons of incomplete fertility and seed shrivelling. It was natural, therefore, for the traditionalists to overlook the potential and stay clear of working with the new species. But comparisons were always made with the best of the highly developed bread wheats and never with synthesized ABD. It simply did not occur to wheat breeders to examine the fertility of the synthesized ABD. I recall Dr Kilhara stating at a meeting in New York that in the past 30 years his group had synthesized a large number of bread wheats and had not found chromosomal stability in any of them. This had been in response to a report from Dr Muntzing that he had found excellent chromosomal stability in one of the fertile triticale lines obtained from Dr Zillinsky.

Fortunately, Dr Sanchez-Monge in Spain and Dr Kiss in Hungary continued their pioneering work on the improvement of triticale. At Winnipeg, in order to look at possible uses for triticale, seed of the triticale we had introduced from Japan was increased. This was a *Triticum persicum* × *Secale cereale* hexaploid. The first farm field was sown in 1961 and the farmer growing the species reported a yield considerably higher than yields obtained from surrounding wheat fields. For the next several years this primary triticale was grown under contract on more than a thousand acres annually to provide seed for testing by a distillation industry and for large-scale animal feeding trials. In each year a number of the best fields averaged 50 bushels per acre, which compared favourably with the best wheat yields in the district.

One phenomenon we noted was that the yields from large farm fields were considerably higher than those obtained from our small replicated experimental plots. We concluded that the large pollen mass over a large farm field would provide for an increase in fertility over that obtained from small plot areas.

With the release of the variety Rosner, which was a considerable improvement over the primary triticale, the contracting farmer recently reported that in his opinion, over the last 4 years Rosner was close to 25% higher in yield than the recommended varieties of wheat, Manitou and Neepawa, under comparable treatment.

A major milestone in the improvement of triticale occurred in 1964 when Dr Borlaug launched the triticale program at CIMMYT. This was a milestone because at least in North America, it brought an aura of respectability to triticale research. Far more important, it expanded tremendously the total research effort, and it brought into play the vast fund of experience that the CIMMYT group had attained in improving the bread wheats.

The speed with which many of the difficult problems were at least partially resolved was nothing short of phenomenal. The improvement in both fertility and seed density, and the broadening of the genic base led to a rapid increase in yields.

By 1971, Zillinsky and Borlaug, in their research Bulletin #17, reported as follows:

> "Although average yields in Triticale have increased substantially during the past two years, they are not yet competitive with the best commercial dwarf Mexican varieties."

But the data they provided showed that at El Batan and Toluca in 1969 the top-yielding triticale outyielded the top-yielding wheat variety by 327 kg/ha. Similarly, at Toluca in 1970 the top triticale outyielded the top wheat by 1137 kg/ha, and at El Batan the top triticale outyielded the top wheat by 407 kg/ha.

Before either Dr Borlaug or Dr Zillinsky take me to task for not providing some qualifying statements, I should add that at El Batan they suspected that wheat suffered more than triticale from residual effects of atrazine, and also that only half the recommended rates of fertilizer was used in order that the triticales would not lodge.

Since coming to this symposium I have seen the 1973 yield results at CIANO where the full recommended rates of fertilizers were used. Thirty-one strains of triticale outyielded the highest yielding bread wheat and durum wheat controls, and some of these by a considerable margin: in exp. 2 by 1069 kg/ha; in exp. 3 by 1107 kg/ha; in exp. 5 by 1125 kg/ha; and in exp. 7 by 1198 kg/ha. The top triticale yielded 8352 kg/ha.

I was also shown the data on the performance of triticale selections at Tulelake, California, for 1973. The top triticale yielded 9890 kg/ha as compared with 8170 kg/ha for the top wheat; or, in other words, the top triticale was 21% higher than the top wheat.

At Winnipeg in 1973, the top-yielding triticale outyielded our highest yielding feed wheat Glenlea by 18% and the variety Rosner by 70%.

I have focussed attention on advances in yield, because unless the new cereal crop will produce more grain on the existing land surface of the earth than competitive cereals and in particular, wheat, it is highly unlikely that it would have a future. The question of acceptable quality of the grain need not be repeated here, other than to re-emphasize the consensus reports that it should be able to replace wheat either as a food or a feed and because of its higher lysine content, be nutritionally superior.

Triticale is already being grown commercially in Spain, and its use will expand as the breeding program expands. This is equally true in Hungary. Dr Kiss clearly indicated why triticale is being grown commercially in his country.

The striking performance of triticale in Ethiopia reported by Mr Hailu Gebremariam suggests that the current introductions he tested are ready to be grown at the farm level.

Dr Srivastava provided excellent evidence for the growing of triticale in parts of the Himalayas, and his work should be supported. More breeding work is required before triticale will be ready for release in other parts of India.

But I have rambled long enough. In my opinion, over the next 15 years, yields of triticale will improve much more rapidly than those of wheat and should plateau at a level approximately 50% higher than those of wheat. This is no idle speculation. Surely the phenomenal improvement that has taken place in triticale in 10 short years, starting from a very narrow genetic base, and on a very modest scale as compared with the bread wheats, should clearly indicate that with rapidly expanding programs and a quickly widening genetic base, with improved fertility and seed density, with improving world wide cooperation, the improvements over the next 15 years will greatly surpass all improvements that so far have been attained.

In 15 years, triticale will have begun to seriously compete with the bread wheats as one of the world's most important food crops. This is what I expect to see reported at a triticale symposium to be held in 1988.

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